Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 224 DECEMBER, 1937 No. 6

BUILDING THE 200-INCH TELESCOPE.*

BY

CAPTAIN C. S. McDOWELL, U.S.N.,

Supervising Engineer 200-Inch Telescope.

I feel that I am coming before my peers to render an accounting of a trust.

During the War it was my privilege to be associated with a great group of Scientists and Engineers. We had been assigned the job of devising apparatus and means for detecting and combating the enemy submarines. Today, many of the same group are engaged in devising apparatus for detecting objects farther out in space and developing methods for using most efficiently the completed telescope and its appurtenances. Both our War time and Peace time successes are due to the spirit of coöperation that has animated a large number of persons. It is impossible to give credit to individuals except by making a long list or slighting deserving ones. I do want to point out though, that this enterprise is due to the vision of Dr. George Ellery Hale and the generosity of the Rockefeller Foundation.

The outstanding characteristic of the 200-inch telescope is its great light gathering power, four times that of any other instrument. This permits greater space penetration and clearer spectra analysis of nearer stars.

* Presented at a meeting held Thursday, December 10, 1936.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

The governing principle of design is to permit full use of this greater light gathering power and at the same time take advantage of every minute of time when "seeing" is extraordinary. This means that surfaces, axes, forms, and alignments must remain fixed relative to each other within close

FIG. 1.

Artist's conception of completed 200-inch telescope, installed in Dome.

limits while the telescope is turned in space, also while changes in temperature occur.

The telescope may be divided into the following major components:

(*a*) The optical system which consists of the 200-inch mirror and auxiliary mirrors.

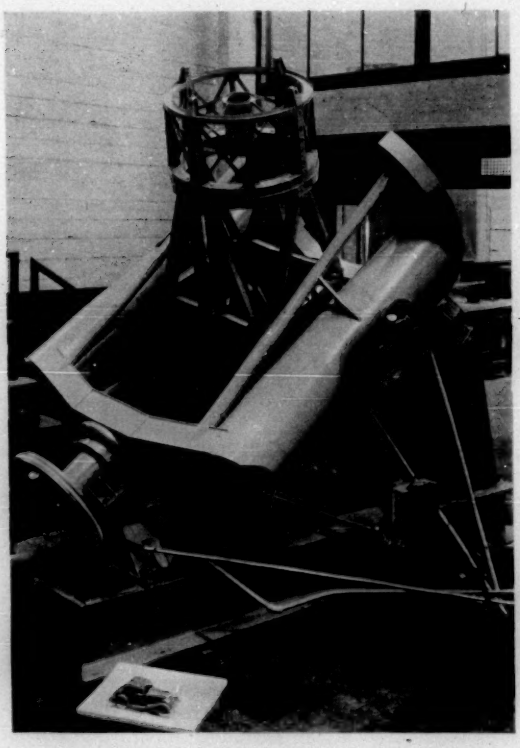
(*b*) The mirror supporting mechanisms.
(*c*) The telescope tube and mounting with the necessary trunnion bearings and declination axis, and bearings at the south and north ends to permit rotation in right ascension.
(*d*) The precision drive and control of position of the telescope.
(*e*) The dome, including foundations and pedestals for the telescope, with a rotating part in which is an opening so that the telescope may be pointed through it toward any object in the Heavens.

It is desired that each of these major parts be given equal attention and that the final design and construction be carried out so as to coördinate all parts and provide the best complete apparatus that can be built at this time, utilizing to the fullest the best present-day knowledge in the engineering and scientific fields. Advantage is being taken of the active interest and coöperation of engineers and scientists throughout the country to meet these requirements.

In the intervening twenty years since the 100-inch telescope was designed and built, many technical improvements have been made in the various fields that are involved in the design of such an instrument. Some of these developments are: Glass having a low coefficient of expansion, such as the super-pyrex used for the mirror of the 200-inch telescope, which has a coefficient of 0.0000025 per deg. C.; electric welding which permits the building of structures that are both strong and light, and which is used in fabricating the tube, yoke, and mirror cell; alloys having low coefficient of expansion which make it possible to utilize individual supports for the mirror having the same coefficient of expansion as the glass; accurate remote-control mechanism such as is used in elevators, canal locks, etc., and which will be utilized in controlling the movements in right ascension and declination of the telescope; more accurate timing apparatus such as the crystal-controlled or the tuning-fork-controlled electric clocks which will permit a more accurate sidereal clock; and many other general improvements in engineering and technique which will be put to use as well as some interesting technical developments which may be applicable to the new instruments.

It may be of interest to review the reasons for choosing a 200-inch telescope.

FIG. 2.



Scale model of tube and mounting.

The 100-inch telescope had fairly well explored outer space, within the limits of its penetration, and had raised questions that could only be answered by a farther ranging instrument.

It was desirable to incorporate in a new telescope, regardless of size, the technical improvements that had taken place since the last large instrument was built and thereby obtain a more useful instrument.

The 200-inch diameter was chosen more or less arbitrarily, but based partly on the study given to possibilities of large mirror manufacture. During the past year, tests have been made that indicate that this is about as large as it would ever be desirable to build a telescope.

Since the law of diminishing returns applies to large telescopes, insofar as present technique is concerned, it is probable that a larger instrument or even another 200-inch will not be built for a long time.

Hence;

The telescope should be:

Flexible—to meet the demands of many kinds of research and reach all parts of the sky.

Fast optically—to make the most of the relatively rare periods when the "seeing" is good and the 200-inch realizes its real power.

Mechanically as nearly perfect as human skill can make it—so that no research will be hampered by poor performance.

f Ratio—why f 3.3

Since spectroscopic workers prefer to change the primary ratio to f 16 or f 30, the prime focus ratio is chosen only on the basis of the performance of the instrument when used as a large camera to photograph stars or nebulæ.

f .5 was once considered the safe lower limit for large reflectors.

As f ratio decreases:

1. The mirrors are much harder to make.
2. They are more subject to temperature distortion.
3. Due to coma the field becomes very small.

At this time we have new glasses which permit revision of previous limits.

1. Since the new glass doesn't change so much with heating while it is being worked, it is easier to make small f ratio mirrors.
2. Ribbed structure of back of mirror that permits quicker temperature equalization.

3. Ross correctors that give a larger field.

The advantage of f 3.3 over f 5

1. Much faster—exposure time to reach a given magnitude approximately 10/25 of time for f 5.
2. Mechanically a more rigid structure can be built and at a lower cost.

Why not f 3.0?

1. Hard to figure the mirror.
2. The Ross correctors begin to lose effectiveness, hence field becomes too small.
3. While the telescope (regarded as a camera) becomes very fast, actually there is no gain in the ultimate faintness of stars which can be photographed for the sky background limits the exposure time.

Sky Background.

Skylight (permanent aurora, scattered light in our atmosphere, etc.) sets a limit to the exposure time of a telescope.

With fast plates strong sky fog is produced with an f 5 in 90 minutes; f 4 in 58 minutes; f 3.3 in 36 minutes; f 3 in 32 minutes; f 2 in 15 minutes.

These figures give approximately the longest profitable exposure time for the various f ratios. Longer exposures simply build up sky fog with no gain in faintness of the stars photographed.

It turns out that in the case of the 200-inch telescope, using these exposure times, a slightly fainter star can be photographed with an f 4 than with f 3.3 but this difference is too minute to be important. In view of other advantages f 3.3 was chosen.

V. 19

MIRRORS.

The mirror is made of glass in the form of a parabolic surface with a grid back having thirty-six individual pockets in the back for support mechanisms. The depth of the glass between the ribs is approximately 4 in. The ribs are 21 in. average depth and about 4 in. thick, so that all points within the glass are not greater than 2 in. from the surrounding air. The glass is a special boro-silicate material having a low coefficient of expansion, and the structure of the mirror is such that it assumes a uniform temperature throughout in a very short time. The rib construction also provides maximum

stiffness with a minimum of weight. The multiple-support mechanisms take the vertical and side loads at the center of gravity at that particular section and prevent any excessive localized strains and consequent deformations of the glass. The mirror will be ground and polished to a final accuracy of 1/20 of a wave-length throughout its surface or one millionth of an inch.

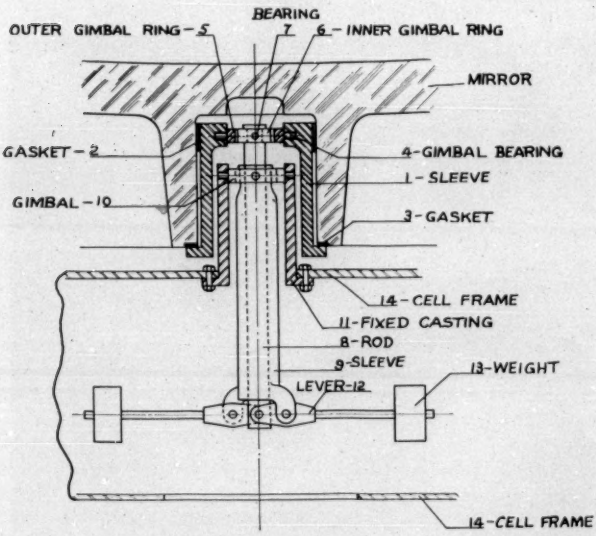
FIG. 3.

One of the 36 individual supports of the 200-inch mirror.

The surface of the mirror is to be coated with aluminum by a process which has been one of the research developments of this project. The use of aluminum as a reflecting medium provides two decided improvements. It has longer life than the silver-surfaced mirrors; exactly how much is not yet known, but whereas the silver-surfaced mirrors on Mt. Wilson had to be resurfaced every six months, aluminized mirrors

have been in use for three years with very little loss of reflectivity. This aluminum also has the great advantage of giving something like 100 per cent. increase in light at the ultraviolet end of the spectrum which, photographically, is a very important part of the spectrum.

FIG. 4.



Simplified outline of mirror support.

SUPPORTING MECHANISM FOR MIRROR.

The 200-inch mirror weighing approximately 33,000 lbs. will be carried on 36 counter balanced supports. Each is so adjusted that it will bear its proportion of the mirror weight at any telescope position (Fig. 4).

The several supports and the balancing arrangement distributes the mirror load evenly and prevents any shifting of the weight from any one support to others as the telescope is

moved. As there is no shifting of the load, there are no sudden or undue strains set up which would cause some slight distortion of the mirror.

The circular pockets cast in the under side of the mirror are carefully bored to receive supporting sleeves. These are cast of an alloy with the same low coefficient of expansion as the glass. The sleeves do not make direct contact with the glass but rest against packing rings which provide some resilience.

A square rod is fixed longitudinally, but free to rotate in the inner ring of a gimbal connection to the pocket sleeve. The gimbal prevents longitudinal motion but allows the rod to swing in any direction relative to the sleeve. The rod is free to slide but not rotate in the sleeve 9, the upper end of which is hung to the supporting casting 11, by means of the gimbal 10. Two levers 12 are fulcrumed in the lower end of the sleeve 9. The outer end of the levers carries weights 13. These can be moved inward or outward and fixed in position, according to the mirror weight to be counter balanced at this support. The inner end of the levers is pivoted to the lower end of the rod 8.

When the telescope is vertical, the weight of each mirror section bears on its packing ring 3. This load is transferred through the sleeve 1 and gimbal 5–6–7 to the rod 8. The resulting downward thrust of the rod is resisted by the levers 12, balanced by the weights 13. The lever reaction causes a downward pull through the sleeve 9 and this pull is transferred through gimbal 10 and casting 11 to the main supporting table or cell 14.

When the telescope points horizontally the weight of the glass is carried through packing ring 2, sleeve 1 and gimbal 5–6–7 to the rod 8. In this case the rod 8 and sleeve 9 act together as a lever, which is fulcrumed at gimbal 10. The load acting on this lever at pivot 7 is balanced by the weights 13. The lever reaction at gimbal 10 is directly transferred to the fixed casting 11.

When the telescope points in any other direction, the counter-balancing acts through a combination of the two systems just described. In actual construction all pivots, bearings, and rollers are of the anti-friction type. The sliding motion of rod 8 in the sleeve 9 is against rollers.

After the mirror is once set up and properly counterbalanced, three of the supports will be locked against further movements by means of screws so as to stabilize the mirror and prevent any motion due to inertia or other causes.

ASTRONOMICAL SPECIFICATIONS.

Certain astronomical requirements or specifications have been established for this telescope and the engineering design is based on meeting or bettering these requirements. Thus, in the design of the tube and mirror supports, the stiffness requirement is set by the allowable departure of the Ross correctors from the optical axis of the instrument. According to the calculations of Dr. Ross, the correctors must be held within 0.040 in. of the axis and must not change more than 0.020 in. during exposure. Assuming an exposure time of one hour, this leads to an overall tolerance of 0.080 in. of the tube and supports combined, in moving from the horizontal to vertical position. The tube has been designed so that when deflections occur the large mirror at the lower end and the auxiliary mirrors and prime focus at the upper end will remain parallel. The computed relative displacement and results from tests of the telescope model show this to be 0.040 in. as compared to an allowable of 0.080 in. The change in angle between the ends, where the allowable change is one minute, will be about ten seconds.

The cage is mounted at the upper end of the tube and carries an enclosure containing the prime-focus optical unit and the auxiliary mirrors for the Cassegrain and Coudé foci. The cage may be turned to certain positions and can be removed and replaced by special cages for any special work that future developments may require. The cage also carries an observer's house 72 in. in diameter, supported separately from the prime-focus house, in which the observer operates when using the prime focus. This arrangement should prove much superior to the usual Newtonian form in which the light is intercepted by a diagonal mirror and brought out at the side of the tube. It conserves light by avoiding an extra reflection and eliminates a mirror which is especially subject to distortion.

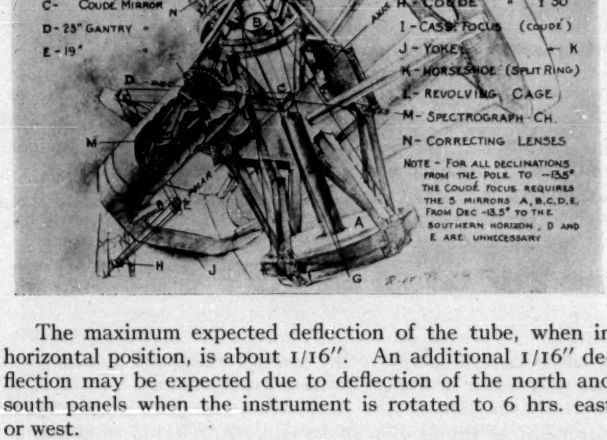
The tube will weigh approximately 250,000 pounds and will be 22 ft. square at the center member and 57 ft. in length.

In general, the function of the tube is to preserve as closely as possible the relative distances and orientations of mirrors comprising the optical system and the plateholder or spectrograph.

Parallel displacements of the above parts due to deflections of the tube have no effect on quality of observing. Angular displacements, however, have to be guarded against.

The tube stiffness is governed by the allowable departure of the Ross correcting lenses from the optical axis of the instrument.

FIG. 5.



The maximum expected deflection of the tube, when in horizontal position, is about 1/16". An additional 1/16" deflection may be expected due to deflection of the north and south panels when the instrument is rotated to 6 hrs. east or west.

Reduced to its simplest form the tube has four sides made up of steel frames. The points at one end are connected by a ring and form the bottom of the tube, and the points at the other end are connected by a ring to form the top of the tube. The middle points are connected together and make a square. Thus the tube is round at both ends and square in the center. The ideal case would be if the center of gravities of all the

loads at the upper and lower ends of the tube fell on the end rings. The actual location is sufficiently close. Under the ideal condition the end rings deflect perpendicular to the axis of the tube. We calculated the area required in the tube members so that the upper and lower ends shifted the same amount, thus there is no relative movement between the upper and lower ends of the tube.

The structure of the south face is different, due to the necessity of a slot the full length of the tube.

DECLINATION AXIS.

The declination axis of the telescope is formed by two trunnions mounted on ball bearings in the 10′-6″ dia. tubular yoke girders and connected to the tube by means of flexible spoke gimbals.

The trunnions are stiff tubes, each mounted on one 27″ × 44″ × 6″ radial and one pair 19″ × 32″ × 5″ angular contact type ball bearings. With the tube in vertical position (declination axis horizontal) the corresponding loads on these bearings are 197,000 lbs. and 65,000 lbs. respectively. With the declination axis vertical the thrust load on the angular contact bearings is about 70,000 lbs.

The bearings are expected to have minimum radial clearance, eccentricity not to exceed 0.0012″ and groove wobble not to exceed 0.0024″.

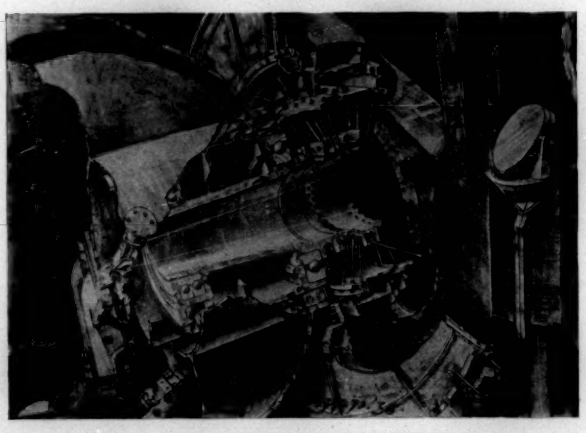
In the ideal case the declination axis should be perpendicular to the polar axis. The allowable tolerance, as set by the astronomers, is 10 sec. of arc or about .012″ on a single bearing. It is seen, therefore, that considerable margin is left by the bearings for some other possible sources of inaccuracies that may occur in the declination axis assembly.

The deflection of the declination axis trunnions at the center line of the flexible spoke gimbals, referred to above, is about .005″. Flexibility of connection between the yoke and the tube is required in order to avoid imposing strains on the tube due to slight inaccuracies in mounting that may occur during assembly of the instrument and due to deflection of parts.

The gimbals on either side of the tube consist of two alloy steel flanges, one attached to the declination axis trunnion

and the other to the tube, joined by 4 rows of ¾" dia. spokes. These spokes, 36 in a row, are arranged in four conical surfaces so that their extensions intersect in one point on the declination axis, thus forming a fulcrum. The gimbal spokes permit slight rotation of the tube about these fulcrums, at the same time restraining it against any other motions. This is due to the well known property of "elastic hinges" made of relatively thin bars to give very little resistance to bending at the same time providing a great resistance to stretching.

FIG. 6.



Cutaway drawing of declination trunnion, 200-inch telescope.

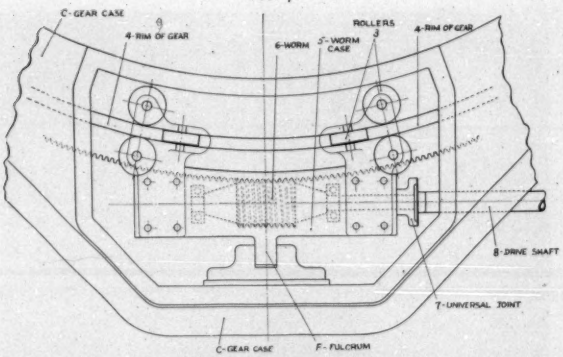
When the dimensions of the parts are properly proportioned the deflections of the gimbal will be the same with the tube in horizontal or vertical position, the deflection being downward at all times. Thus no error is contributed by the flexible gimbals during the motion of the telescope.

In order to avoid the possibility of the centers of the spoke gimbals not being parallel with the top face of the tube, an eccentric tongue and groove fit is provided at the inner ring of the gimbal where it bolts against the trunnion.

The load on the gimbals is about 170,000 lbs. when declination axis is vertical, resulting in stresses of about 8,000 lbs. and 10,000 lbs. per sq. in. in the spokes of the inner and outer row respectively. With the declination axis horizontal the load on the gimbal is 125,000 lbs. and the stresses in the spokes are about 7,000 lbs. per sq. in.

Since the misalignment of the tube and mounting is not expected to exceed one minute of arc, the bending stresses in the spokes due to this misalignment will be small, in the order of 2,000 lbs. per sq. in.

FIG. 7.



Declination worm and gear.

The friction torque of the declination axis bearings, amounting to about 25,000 lbs. ins., is transmitted by six additional spokes in each gimbal. These spokes are arranged in a plane perpendicular to the declination axis.

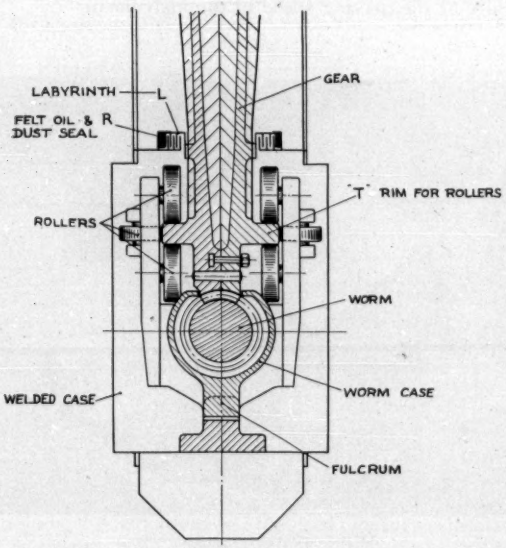
The tube will be balanced about the declination axis and means will be provided for compensating for any changes in weights due to use of different auxiliary mirrors or other attachments.

The tube will be turned in declination by means of a worm and worm-wheel. This worm will be floating so as to maintain its position in relation to the wheel unaffected by deflections in the mounting.

V. 19

The polar axis of the instrument is the instantaneous axis of rotation of that part of the yoke or mounting which carries the declination bearings. It may change its position in space, but if the instrument is to follow properly, it should remain always parallel with the axis of the earth. The yoke or mounting must furnish mechanical support for the tube and

FIG. 8.



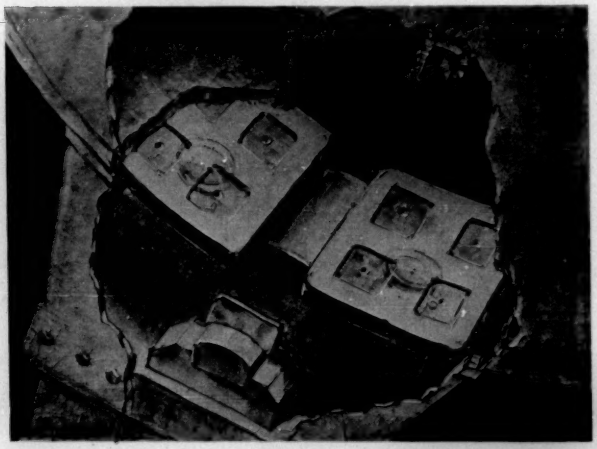
Another view of declination drive.

also establish this axis of rotation—the polar axis—and furnish uniform rotation about that axis. Supported at the north end of the yoke is the horseshoe which is made in this shape in order that the tube may be pointed at the pole. The horseshoe must be supported in some manner to permit smooth and uniform motion while at the same time maintaining the accuracy of alignment of the polar axis. We have

investigated various methods of supporting this horseshoe and it is our belief that apart from very cumbersome mercury floats the only feasible method of support is to float the structure on a film of oil.

Viscous flow of oil is utilized to maintain a film of oil of approximately 0.003 in. between the pads and the horseshoe. Calculations and tests show that the torque required to overcome friction of a north bearing of this type would be about 35 ft.-lb. at the driving speed of the instrument.

FIG. 9.



Oil pad support of north end mounting.

Had we used roller bearings, torque required to overcome the friction at the north end would be about 22,000 ft.-lb. at driving speed which would have resulted in an inadmissible torsional deformation of the yoke.

At the south end we have considered various methods of support, all taking care of the effect of deflections of the yoke on the bearing. Here again the oil bearing has seemed preferable and has been adapted. It has friction torque at driving

speeds of about 15 ft.-lb. as compared to about 7,000 ft.-lb., in case of a double-thrust and radial-load ball bearing.

The yoke, a one-tenth scale model of which is shown, has been designed so as to hold the polar axis correct within 3 sec. of arc. The weight of the yoke is 600,000 lbs., the length 60 ft. 6 inches, the diameter of the horseshoe at the north end is 46 ft. The side members tying the north and south ends together are cylinders 10 ft. 6 inches in diameter. Inside of these cylinders spectrographs or other instruments may be mounted and operated from the Cassegrain Coudé focus.

The form of yoke has been developed to meet the following conditions:

1. Rigidity against bending and twisting.
2. Proper relative stiffness of parts in order to reduce undesirable deflections.
3. Permit observation from 2 deg. above south horizon to 1 deg. below the north celestial pole.
4. Permit rotation about polar axis of 105 deg. each side of the meridian.
5. Bring the Cassegrain Coudé focus to the side to permit use of a large spectrograph.
6. Members that can be easily fabricated, machined, shipped, and erected.

DRIVE AND CONTROL OF THE POSITION OF THE TELESCOPE.

Keeping in mind the importance of taking full advantage of those periods when seeing is at its best, it is desirable to hold the telescope steadily on a star with an image that may be of the order of ¼ second in diameter. This is something like holding a gun pointed on an object two inches in diameter that is twenty miles distant and moving across the line of sight three feet a second. After we have provided accurate worms and worm wheels and arranged their connections to the tube and mounting so as to eliminate errors due to distortion of the tube and mounting, it is necessary to impart the required movements to these mechanisms with smoothness and preciseness. We hope that the apparatus of control which we have laid out will direct the telescope smoothly from one spot in the Heavens to another 1/10 of a second

apart. It is intended to introduce, in the movements imparted to the driving gear, corrections due to refraction as a function of zenith distance, deflection errors as a function of zenith distance not otherwise compensated for, and such residual errors as remain in the right ascension and declination gears.

We will have a primary source of precise movement which will probably be a crystal controlled sidereal clock. There is an interesting development underway in which a guide star in the telescope field can, with its own light, hold the telescope on the desired object. It is possible that automatic guiding in this manner may be applicable in some parts of the Heavens and means will be provided for shifting from the clock to this apparatus when desirable. There are in the offing other developments of new telescope technique which, in my opinion, makes it important to pay more attention to the accuracy of control than has possibly been considered necessary in the past. We are at present installing the tenth scale model as an operating telescope in a dome at the California Institute of Technology in Pasadena. A drive and control similar in principle to that proposed for the full sized telescope will be provided and thoroughly tested on this 20-inch telescope before it is finally adopted for the 200-inch. We have adhered rather closely to the idea of getting the answer to our problems, where possible, by the use of models and it is believed that this procedure is very desirable in a project of this nature.

V.2
19

DOME.

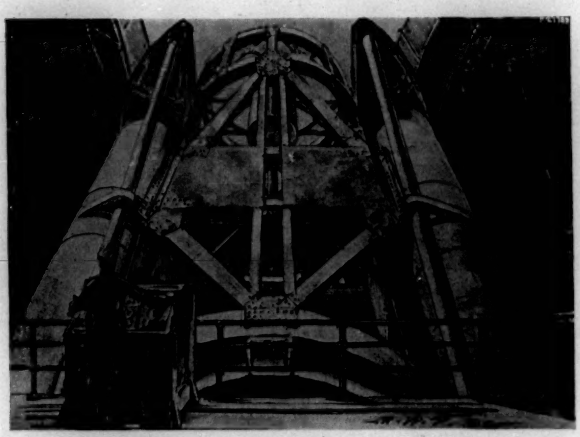
It is necessary, of course, to tie the telescope to the ground, to provide covering for protection from the weather, and to provide storage for auxiliary apparatus and to provide photographic rooms and other facilities for operating the telescope. These functions are all included in the dome.

The dome itself will be a building some 135 ft. in diameter and approximately this height from the ground level to the top. The stationary part up to the operating floor will be 26 ft. above the ground and will be made of concrete and steel. The upper part of the dome must rotate and carry an opening for the line of sight of the telescope with a shutter that can

be closed when the telescope is not in use. This rotating part of the dome will be mounted on tracks and must rotate smoothly so as not to transmit vibrations through the structure to the telescope.

The foundations and pedestals for the telescope and its mounting will have a substructure of concrete with the steel sub-base and pedestals. All of this structure will be separated and isolated from the foundations of the dome itself.

FIG. 10.



Telescope pointing at Polaris.

At present the foundations for the dome and the telescope sub-base are completed and the steel sub-base and steel columns and girders for the stationary part of the dome are installed. The concrete floors of the dome are being poured and the outer wall of the lower dome is about to be built. This wall will be double with a 12-inch ventilated air space between an outer 1½″ gunite wall and an inner insulated wall. This wall has been designed to keep the lower part of the dome slightly cooler than the upper part and to permit a rapid dissipation of heat from the outer wall so as not to

FIG. 11.

Observing at the Cassegrain.

cause local disturbance and interference with "seeing" in the early evening.

We have been testing models of the upper rotating dome for the past few months and applying the laws of similitude in order to develop the simplest and best structure. These tests are not quite finished but it appears that we can utilize a monocoque design which, except for the arched girders at the shutter opening, will consist of welded bumped steel plates, self supported.

We have been working about a year on Palomar Mountain in San Diego County, California, preparing a site and utilities for the operation of the telescope. We have completed our water supply storage and distributing system; have built a power plant for necessary electric requirements; installed a machine shop to take care of local maintenance and repair facilities for the telescope; have built quarters for the operating personnel; have built a twenty foot dome for an 18″ Schmidt telescope, which is now in operation, and have had built for us a good high gear road from the valley below. As one stands today on the site of the telescope at fifty seven hundred feet elevation and looks around at this rather unique location, there is a feeling that an observatory is coming into being.

I have skimpily covered or passed over entirely many of the details of this undertaking, but the foregoing examples should serve to show, in general, the scope of the project. We have reached that happy period in which we no longer have any doubts about constructing a really fine instrument which will do all that is required of it. The entire group concerned with the design and building of this telescope hope to make it a fine monument to that long line of telescope builders which began with Galileo and Newton.

Chemistry and the Progress of Mankind.—An increase of more than 53 per cent. in registration under courses in the chemistry department of the University of Pennsylvania in the past five years is reported in a twenty-two-page illustrated pamphlet released by the University's Bicentennial Committee. The explanation of this rapidly expanding interest in chemistry as a career is found, among other reasons, in the greatly increased importance of chemistry in virtually all manufacturing industries, as well as in medicine and agriculture. The pamphlet traces the development of chemistry from the accidental discovery of glass 3,000 years ago by Phœnician sailors in Syria, through the Industrial Revolution and the researches of Cavendish, Priestley, Scheele, Lavoisier, Faraday and Pasteur, to the present. The range of industries today dependent upon chemical research and chemical production, it shows, runs from the fabrication of stream lined stainless steel locomotives to that of the daintiest of rayon lingerie; from the compounding of automobile tires and motor fuel to the compounding of a layer cake.

R. H. O.

THE REFRACTIVITY INTERCEPT AND THE SPECIFIC REFRACTION EQUATION OF NEWTON. II. THE ELECTRONIC INTERPRETATION OF THE REFRACTIVITY INTERCEPT AND OF THE SPECIFIC REFRACTION EQUATIONS OF NEWTON, EYKMAN AND LORENTZ-LORENZ.

BY

S. S. KURTZ, JR.,* AND A. L. WARD.†

(*Concluded from November issue.*)

IV. APPLICATION OF THE NEWTON, LORENTZ-LORENZ AND EYKMAN EQUATIONS TO REFRACTIVE INDEX AND DENSITY DATA FOR AIR UNDER PRESSURE.

Data for the refractive index and density of gases are frequently used in testing refraction equations. For example, van Vleck (Ref. 17, p. 15) refers to the data of Magri [21] as proof of the accuracy of the Lorentz-Lorenz equation for gases. The last column of Table III shows that the Eykman equation fits Magri's data for air under pressure as accurately as does the Lorentz-Lorenz equation. This confirms the view of Jenkins,[19] previously referred to, that a variety of equations can be written all of which will equally well represent data for the refractive index and density of a gas. Further consideration will not be given to such data since they do not provide a sufficiently critical basis for the comparison of refraction equations.

V. TEST OF THE LORENTZ-LORENZ AND EYKMAN EQUATIONS WITH EXPERIMENTAL DATA FOR ORGANIC COMPOUNDS IN THE LIQUID STATE.

The constants of the Lorentz-Lorenz and Clausius-Mosotti equations are supposed to be independent of external effects such as temperature and pressure and are supposed to be constant for any group of isomers such as the isomeric heptanes. Six independent types of experimental data are therefore available for checking the internal field strength hypothesis upon which these equations are based. The data

* Development Engineer, The Sun Oil Co.

† Manager, The Chemical Laboratories, The United Gas Improvement Co.

[21] L. Magri, *Physikalische Zeitschrift*, 6, pp. 629–632, 1905.

TABLE III.

Density and Refractive Index of Air Under Pressure According to Data of Magri.[21] *

Temp. °C.	Size Container Uned.	d †	n	$\frac{n^2-1}{d}$	$\frac{n^2-1}{n^2+2d}$	$\frac{n^2-1}{n+0.4d}$
				× 10⁶	× 10⁶	× 10⁶
0	Small	1	1.0002929	585.9	195.3	418.5
14.5	"	109.56	1.03242	601.4	196.2	419.9
14.9	"	176.27	1.05213	602.0	195.4	418.0
			Max. Dev.	21.1	0.9	1.9
			%	3.6%	0.46%	0.45%
16.3	Large	16.67	1.004877	586.6	194.9	417.5
16.6	"	93.64	1.02767	599.2	196.0	419.7
16.9	"	154.78	1.04578	605.1	195.6	418.5
			Max. Dev.	18.5	1.1	2.0
			%	3.15%	0.56%	0.48%

* Magri's tables contain data for many more densities than here given.

† d = density relative to air under standard conditions.

for the effect of temperature and pressure will also be used to check the Eykman equation.

(*a*) *Effect of Temperature upon Refractive Index and Density.*

Lorentz in his original publication [6] calculated the temperature coefficient of the refractive index by means of the $(n^2 - 1)/(n^2 + 2)d$ = constant formula and compared the calculated coefficients with the observed temperature coefficient. In general, the observed change of refractive index with temperature was *less* than that calculated by the formula. Eykman [13, 22] in his monumental experimental researches demonstrated that the effect of temperature upon refractive index and density could be represented by the equation

$$(6) \qquad (n^2 - 1)/(n + 0.4)d = \text{constant}.$$

The data in Table IV show that for hydrocarbons the Eykman equation is in very good agreement with the experimental data whereas the Lorentz-Lorenz and Gladstone and

[22] J. F. Eykman, Recherches Refractometriques, Naturkundige Verhandlingen Hollandsche Maatschappij Wetenschappen, Edited by A. F. Holleman, Printed in French by De Erven Loosjes, Harlem, 1919.

TABLE IV.

Data of Eykman Comparing Molecular Refraction Formulae.[22]

Substance.	T	Mol. Refraction for Ha.			% Change in Mol. Ref.		
		G. & D.	L. & L.	Eyk.	G. & D.	L. & L.	Eyk.
Hexane	14	48.78	29.76	65.24	−0.23	+0.23	+0.03
	44.95	48.67	29.83	65.26			
Paraffin $C_{20}H_{42}$	38.3	157.43	94.48	208.95	−0.60	+0.54	−0.06
	136	156.50	95.00	208.82			
Paraffin $C_{33}H_{44}$	80.4	250.07	150.22	332.05	−0.32	+0.33	−0.02
	140	249.27	150.70	331.97			
Cetene	20.2	125.61	75.24	166.57	−0.73	+0.75	−0.04
	140.5	124.70	75.80	166.51			
Benzyl toluene	14.7	103.69	59.70	135.29	−0.55	+1.18	+0.12
	137	103.13	60.41	135.46			

Dale equations are about equally in error, the Lorentz-Lorenz equations indicating too great a change in n with temperature and the Gladstone and Dale equation too small a change with temperature. For hydrocarbons and for the range 10 to 30° C. the Eykman equation is equivalent (Ref. 1) to

$$\left[\frac{\Delta n_c}{\Delta d_c}\right]_{t_1}^{t_2} = 0.60. \tag{51}$$

This ratio for the refractive-index-density increments has been amply verified with other data from the literature,[23] therefore it may be said that the data for the effect of temperature on refractive index and density of liquid hydrocarbons supports the Eykman, not the Lorentz-Lorenz equations or the internal field strength hypothesis from which the latter equation was derived.

(*b*) *Effect of Temperature upon Dielectric Constant and Density.*

The close relation between the square of the refractive index and the dielectric constant for non-polar compounds

[23] A. L. Ward, S. S. Kurtz, Jr. and W. H. Fulweiler, Chapter on Density and Refractive Index in "Science of Petroleum." Oxford University Press (in preparation), also tables of refractive index and density data for pure hydrocarbons, to be published elsewhere.

such as the hydrocarbons makes it seem highly probable that an equation of the Eykman form

$$\frac{(\epsilon - 1)}{(0.4 + \sqrt{\epsilon})}\frac{1}{d} = \text{constant} \qquad (7)$$

will accurately represent the effect of temperature on density and dielectric constant. The excellent data of Dornte and Smyth [24] for the normal paraffins show that this is in fact the case. Table V gives the effect of 100° C. change in tempera-

TABLE V.

Comparison of the Clausius-Mosotti Dielectric Constant Equation with the Eykman Type Equation for Normal Paraffins with Change in Temperature.[24]

Hydrocarbon.	$\frac{\epsilon-1}{\sqrt{\epsilon}+0.4}\frac{1}{d}=C_1$.					$\frac{\epsilon-1}{\epsilon+2}\frac{1}{d}=C_2$.				
	t °C.	C_1.	t °C.	C_1.	Δ per 100° C. %	t °C.	C_2.	t °C.	C_2.	Δ per 100° C. %
Pentane..	−90	0.7663	+10	0.7668	−0.07	−90	0.3465	+10	0.3504	+1.13
Hexane...	−90	0.7574	+10	0.7603	+0.38	−90	0.3427	+10	0.3466	+1.14
Heptane..	−90	0.7537	+10	0.7567	+0.40	−90	0.3405	+10	0.3443	+1.12
Octane...	−50	0.7479	+50	0.7510	+0.41	−50	0.3385	+50	0.3423	+1.12
Nonane...	−50	0.7470	+50	0.7497	+0.36	−50	0.3376	+50	0.3413	+1.10
Decane...	−30	0.7457	+70	0.7503	+0.62	−30	0.3373	+70	0.3416	+1.27
Undecane.	−10	0.7450	+90	0.7481	+0.42	−10	0.3371	+90	0.3408	+1.10
Dodecane.	−10	0.7414	+90	0.7456	+0.57	−10	0.3353	+90	0.3393	+1.19
Mean....					0.45*					1.15

* Exclusive of Pentane.

ture on the constant in Clausius-Mosotti equation and the constant of equation (7) for the normal paraffins from hexane to dodecane. This table shows that equation (7) fits the data more accurately than the Clausius-Mosotti equation.

These accurate data for the effect of temperature on the dielectric constant of liquid non-polar hydrocarbons provide further evidence against the internal field strength hypothesis upon which the modern derivation of the Clausius-Mosotti equation is based.

[24] R. W. Dornte and C. P. Smyth, *J. A. C. S.*, **52**, pp. 3546–3552, 1930.

(c) *The Effect of Pressure on Refractive Index of Hydrocarbons in the Liquid State.*

Bridgman in his text on the "Physics of High Pressure" [25] states that there has been no significant work on the effect of pressure on refractive index since that of Roentgen and Zehnder.[26] These authors determined the compressibility of a series of organic liquids and the effect of pressure on the refractive index of these liquids. They then used the $(n^2-1)/(n^2+2)d$ = constant and $(n-1)/d$ = constant equations to calculate the density and compressibility from the refractive index measurements. Table VI shows that the

TABLE VI.

Data of Roentgen and Zehnder on Compressibility of Organic Compounds in the Liquid State.[26]

Compound.	Temp. °C.	Observed Compressibility.	Deviation of Calculated Compressibility from the Observed Compressibility.	
			Calc. by $\frac{n-1}{d}=c$ formula from pres. coefficient of ref. index.	Calc. by $\frac{(n^2-1)\,1}{(n^2+2)\,d}=c$ formula from pres. coefficient of ref. index.
Thiophene free benzene	17.90°	91.7×10^{6}	$+7.7\times10^{6}$	-7.0×10^{6}
Purified CS_2	18.05	89.5	+13.8	−7.6
Ethyl ether	18.15	163.8	+ 7.6	−9.8
Methyl alcohol	17.60	119.5	+ 4.9	−6.5
Ethyl alcohol	19.30	111.4	+ 5.1	−6.8
n-propyl alcohol	17.60	96.9	+ 4.7	−6.6
n-butyl alcohol	17.50	90.5	+ 4.8	−6.3
Isobutyl alcohol	18.10	98.4	+ 5.3	−6.6
Amyl alcohol	17.60	90.4	+ 5.3	−6.1

compressibility calculated from the Lorentz-Lorenz and Gladstone and Dale equations are about equally divergent from the true values, but that the sign of the deviations are opposite. The Eykman equation gives a relation between density and refractive index of liquids almost exactly intermediate between the Lorentz-Lorenz and Gladstone and Dale relations, as shown in Table IV. The data of Roentgen and

[25] P. W. Bridgman, "The Physics at High Pressure," p. 369. MacMillan Co., New York, 1931.

[26] W. C. Roentgen and L. Zehnder, *Wied. Ann.*, 44, 24, 1891.

Zehnder must therefore be in close agreement with the Eykman equation. Unfortunately, Roentgen and Zehnder did not publish their data in a form which is convenient for recalculation by the Eykman equation. In spite of this difficulty there can be no doubt that Roentgen and Zehnder data are definitely in support of the Eykman equation and against the Lorentz-Lorenz or Gladstone and Dale equations.

(d) The Effect of Pressure on the Dielectric Constant of Hydrocarbons in the Liquid State.

The work of Kyropoulos [27] and of Bridgeman's associates, Chang [28] and Danforth [29] have been interpreted as indicating that the Clausius-Mosotti equation most nearly expressed the data for the effect of pressure on dielectric constant. Tables VII and VIII show that for toluene and

TABLE VII.

The Effect of Pressure on the Dielectric Constant of Toluene at 30 ± .03/C. According to Z. T. Chang.[28]

Pressure kg./cm.²	ϵ 2000 ~	d gm./cc.	$\frac{(\epsilon-1)}{(0.4+\sqrt{\epsilon})d}\cdot\frac{1}{d}$ *	$\frac{(\epsilon-1)}{(\epsilon+2)}\cdot\frac{1}{d}$ *	$\frac{\sqrt{\epsilon}-1}{d}$ *	$\frac{\epsilon-1}{d}$ *
1	2.373	0.858	.8248	.3661	.6308	1.601
500	2.440	0.891	.8237	.3643	.6311	1.617
1000	2.486	0.912	.8242	.3632	.6324	1.628
4000	2.684	1.000	.8263	.3596	.6380	1.684
6000	2.772	1.042	.8235	.3564	.6384	1.702
8000	2.849	1.072	.8261	.3557	.6419	1.726
9500	2.900	1.088	.8304	.3564	.6461	1.747
Maximum difference from initial	0.527	0.230	+.0056	−.0104	+.0153	+0.146
% of constant			+0.68	−2.65	+2.43	+9.12
Equiv. $\Delta\epsilon$ * based on 1000 to 4000 increment			+0.015	−0.072	+0.049	+0.20

* These calculations were made by the authors. The other data in this table are from the original reference.

pentane equation (7) in the Eykman form, yields a constant with a maximum deviation of not over 1.2 per cent. The observed deviation from the Eykman constant corresponds,

[27] S. Kyropoulos, *Zeit. Phys. Chem.*, **40**, 507 (1926).

[28] Z. T. Chang, *Chinese Journal of Physics*, **1**, Issue No. 2, pp. 1–55 (1935).

[29] W. E. Danforth, Jr., *Physical Reviews*, **38**, pp. 1224–35 (1935).

TABLE VIII.

The Effect of Pressure on the Dielectric Constant of Pentane and Carbon Disulphide According to W. E. Danforth, Jr.[39]

Substance.	Pressure in Atmosphere.	ϵ 30° C.	d 30° C.	$\frac{(\epsilon-1)}{(0.4+\sqrt{\epsilon})}\frac{1}{d}$. †	$\frac{(\epsilon-1)}{(\epsilon+2)}\frac{1}{d}$.
Pentane	1	1.82	0.613	0.7648	0.356
	500	1.90	0.664	0.7623	0.354
	1000	1.96	0.701	0.7608	0.352
	2000	2.03	0.743	0.7596	0.349
	4000	2.12	0.796	0.7599	0.345
	6000	2.19	0.835	0.7580	0.342
	8000	2.24	0.865	0.7557	0.340
	12000	2.33	0.907	0.7613	0.339
Δ (1–8000)				−0.0091	−0.016
Δ (1–12000)				−0.0035	−0.017
Max. Deviation % †				1.2%	4.77%
Max. Deviation Equivalent $\Delta\epsilon$ *				0.019	0.064
Carbon Disulphide	1	2.61	1.241	0.6435	0.281
	500	2.74	1.291	0.6558	0.284
	1000	2.82	1.332	0.6572	0.284
	2000	2.94	1.394	0.6580	0.282
	4000	3.11	1.487	0.6557	0.278
	6000	3.23	1.550	0.6548	0.275
	8000	3.33	1.601	0.6541	0.273
	12000	3.52	1.689	0.6555	0.270
Δ (500–12000)				−0.0003	−0.014
Δ (1–12000)				+0.0120	−0.011
Max. Deviation % †				+1.9%	−5.0%
Max. Deviation Equivalent $\Delta\epsilon$ *				+0.05	−0.17

* Based on increment from 2000 to 4000 atmospheres.

† Calculated by the authors.

for these hydrocarbons, to approximately ± 0.01 in the dielectric constant, which is not far from the limits of experimental accuracy which may reasonably be expected in the measurement of dielectric constant under high pressure. The deviations in the case of the Clausius-Mosotti constant are three to four times as great and well beyond the limits of experimental uncertainty.

In the case of carbon disulphide there is a change of approximately 2.0 per cent. in the Eykman constant between 1 and 500 atmospheres, but from 500 to 12,000 atmospheres the deviation is negligible. The deviation for the Clausius-Mòsotti formula is again about three times as large as for the Eykman formula.

One may summarize the evidence given in paragraphs (*a*), (*b*), (*c*) and (*d*) just presented, by saying that the Eykman form of equation represents the effect of either pressure or temperature upon either refractive index or dielectric constant with a degree of accuracy closely approaching the accuracy of the experimental data themselves. The Lorentz-Lorenz equation does not fit the data, and the corollary of this statement is that the evaluation of "internal field strength," as carried out by Lorentz in the derivation of his equation, is wrong.

(*e*) *Relation Between Density and Either Dielectric Constant or Refractive Index of Hydrocarbon Isomers.*

The inability of the Lorentz-Lorenz or Clausius-Mosotti equations to relate correctly the properties of isomeric hydrocarbons provides two further types of experimental evidence bearing on their validity. Very accurate data are available for the physical properties of the isomeric heptanes, hence these data are especially valuable for such a study. In Part I of this paper [1] it was shown that the Newton equation is approximately four times as accurate as is the Lorentz-Lorenz equation for expressing the relationship between refractive index and density at 20° C. for hydrocarbon isomers. Table IX which is calculated from the data of Smyth and Stoops [30] show that a dielectric constant equation based on the Newton equation is about twice as accurate as is the Clausius-Mosotti equation for expressing the relationship between density and dielectric constant at 20°.

In the case of an homologous series, notwithstanding the fact that the change in the carbon-hydrogen ratio introduces further complication, the Newton type dielectric constant equation represents the experimental data fairly well. As shown in Table X, which is based on the data of Dornte and Smyth [24] for the normal paraffins from pentane to dodecane, the Newton type equation is about seven times as accurate as is the Clausius-Mosotti equation in expressing the relationship between density and refractive index for an homologous series.

[30] Smyth and Stoops, *J. Am. Chem. Soc.*, **50**, 1883, 1928.

TABLE IX.

Comparison of Clausius-Mosotti Dielectric Constant Equation with the Newton Type $\frac{(\epsilon - 1)}{d}$ *Equation Applied to Data for Heptanes at 20° C. (Ref. 30).*

(Ave. $\epsilon = 1.9298$; $d = 0.6860$.)

Hydrocarbon.	$\frac{\epsilon - 1}{d}$.	Δ−%.	Δ+%.	$\frac{\epsilon - 1}{\epsilon + 2}\frac{1}{d}$.	Δ −%.	Δ+%.
2,2-dimethyl pentane	1.3582		0.23	0.3469		0.57
2,4-dimethyl pentane	1.3595		0.33	0.3471		0.64
2-methyl hexane	1.3581		0.23	0.3463		0.41
n-heptane	1.3605		0.41	0.3462		0.37
3-methyl hexane	1.3537	0.10		0.3445	0.11	
2,2,3-trimethyl butane	1.3494	0.41		0.3434	0.44	
3,3-dimethyl pentane	1.3525	0.18		0.3441	0.23	
2,3-dimethyl pentane	1.3550	0	0	0.3438	0.32	
3-ethyl pentane	1.3481	0.51		0.3421	0.81	
Arith. mean	1.3550			0.3449		
Mean dev. of A.M.	0.27%			0.43%		
Equiv. ϵ of M.D.	0.0025			0.0054		
Std. dev. Prob. error of individual	0.19%			0.34%		
Equiv. ϵ for prob. error of individual	0.0018			0.0030		

TABLE X.

Comparison of the Clausius-Mosotti Dielectric Constant Equation with the Newton Type $\frac{(\epsilon - 1)}{d}$. *Equation Applied to Data for Normal Paraffins (at 20° C.) (Ref. 24).*

(Ave. $\epsilon = 1.9494$; $d = 0.7016$.)

	$\frac{\epsilon - 1}{d}$.	Δ−%.	Δ+%.	$\frac{\epsilon - 1}{\epsilon + 2}\frac{1}{d}$.	Δ−%.	Δ+%.
Hydrocarbon						
Pentane	1.3492	0.30		0.3509		2.39
Hexane	1.3485	0.35		0.3468		1.20
Heptane	1.3534		0.01	0.3447		0.58
Octane	1.3508	0.18		0.3420	0.20	
Nonane	1.3534		0.02	0.3407	0.58	
Decane	1.3564		0.24	0.3399	0.82	
Undecane	1.3570		0.28	0.3388	1.14	
Dodecane	1.3569		0.28	0.3378	1.43	
Arith. Mean	1.3532			0.3427		
Mean dev. of A.M.	0.21%			1.04%		
Equiv. ϵ for M.D.	0.0020			0.013		
Std. dev. Prob. error of individual	0.17%			0.88%		
Equiv. ϵ for prob. error of individual	0.0016			0.011		

(f) Conclusions Derived from Sections III to V Inclusive.

The discussion of the derivation of the Lorentz-Lorenz equation presented in Section III, coupled with the experimental data of Section V, which show that the Lorentz-Lorenz and Clausius-Mosotti equations are not accurate generalizations of the data for liquid non-polar dielectrics, force the authors to conclude that the Lorentz-Lorenz and Clausius-Mosotti equations are not valid. On the other hand, the data presented in the preceding paragraphs show that the Eykman, Newton and Sellmeier-Drude equations all have specific fields of usefulness in which they accurately represent the available experimental data. Therefore, in the balance of this paper the Eykman equation will be used for the effect of pressure or temperature on n or ϵ, and equations in the Newton form will be used for relations at constant temperature and pressure. The Sellmeier-Drude form of equation will be used for the correlation of dispersion data.

VI. THE INTERPRETATION OF REFRACTIVE INDEX DATA FOR HYDROCARBONS ON THE BASIS OF ELECTRON THEORY.

In the preceding portion of this paper, data and theoretical arguments have been presented on the basis of which the Sellmeier-Drude type of refraction equation has been chosen for use in the study

$$n^2 - 1 = \frac{Ne^2}{\pi m_0(V_0^2 - V^2)} \tag{14}$$

of the refracting properties of hydrocarbons.

(a) The Relation Between the Sellmeier-Drude Dispersion Equation, and Modern Dispersion Equations Based on Quantum Mechanics.

Since the Sellmeier-Drude type of dispersion equation is based entirely on the concepts of classical physics, one might well hesitate to expend much effort on the application of these equations to date for organic compounds except for the fact that the experts in this field in general agree that the dispersion equations based upon quantum mechanics have the same form of dependence upon frequency as does the

Sellmeier-Drude equation (8), (14). (See Ref. 17, p. 361, also references 10, 18, 31.)

This is briefly but clearly discussed by Hückel.[10] The general idea is, first that the frequency of vibration V_0 which occurs in the classical equations is considered as arising from a transition between two electron states having different energies, and second, that a coefficient must be introduced to allow for the frequency with which such transition can occur. If E_b is the energy of the state *before* the transition and E_a the energy of the state *after* the transition one may write

$$(52) \qquad V_0 = V_{ba} = \frac{E_b - E_a}{h} = \frac{\Delta E}{h},$$

where h is Planck's constant. If we define N_0 as equal to the actual number of electrons per ml. that are capable of undergoing the transition $E_a \rightleftarrows E_b$ then $N_0 f_{ba}$ may be taken as the effective number of "dispersion electrons" N, or the "strength of the oscillators." The coefficient f or f_{ba} is dependent upon the probability of transition between the two states b and a. It seems probable that, in the case of hydrocarbons, N_0 is the sum of the valence electrons, and this will be tentatively assumed. Therefore one may write

$$(53) \quad N = f_{ba} N_0 = f_{ba} \cdot (\text{number of valence electrons/ml.}),$$

$$(54) \qquad n^2 - 1 = \frac{e^2 N_0}{\pi m_0} \sum \frac{f_{ba}}{(V_{ba})^2 - V^2}.$$

For the consideration of hydrocarbons it has been found possible to obtain a good first approximation on the assumption that the electrons associated with the C − C and C − H bonds behave similarly, i.e. that in saturated hydrocarbons it is not necessary to distinguish between the various types of formula bonds. With further development of this type of analysis and for a complete study of the change in carbon-hydrogen ratio in ascending an homologous series, it will become necessary to make a distinction between the two types of bonds.

[31] W. Heitler, "The Quantum Theory of Radiation," p. 133. Oxford University Press, London, 1936.

Even in a preliminary analysis it is necessary to distinguish between the electrons in double and single carbon-carbon bonds. Therefore, the subscripts I and II will be used to distinguish symbols referring to single (C − C) and double (C = C) bonds respectively. Where these subscripts are used summation of the whole term for all characteristic vibrations will be understood. One may, therefore, write equation (55) for compounds having only single bonds

$$(55) \qquad n^2 - 1 = \frac{e^2}{\pi m_0}\left[\frac{N_{0I} f_{I_{ba}}}{(V_{I_{ba}})^2 - V^2}\right]$$

and equation (56) for compounds having both single and double bonds.

$$(56) \quad n^2 - 1 = \frac{e^2}{\pi m_0}\left[\frac{N_{0I} f_{I_{ba}}}{(V_{I_{ba}})^2 - V^2} + \frac{N_{0II} f_{II_{ba}}}{(V_{II_{ba}})^2 - V^2}\right].$$

These equations will be used later in connection with the discussion of the experimental data, particularly for olefins.

Mitchell and Zemansky,[32] discussing the work of Ladenburg,[33] state "The f value associated with a spectral line emitted by an atom can be regarded as a measure of the degree to which the ability of the atom to absorb and emit this line resembles such an ability on the part of a classical oscillating electron." The term f_{ba} used in our discussion similarly measures the ability of valence electrons in hydrocarbons to absorb and emit in a manner similar to the classical oscillating electron. It has also been shown that f is related (1) to the probability per unit time that a transition will occur with absorption of a quantum $h\nu$ and (2) to the life time of the atom in the resonance state.[9, 10, 32]

From consideration of equations (52) to (56) inclusive, it is clear that if one obtains N and V_0 by solution of the single term classical equation (such as equation (14)) it will be possible to interpret these values in terms of f_{ba} and ΔE. It is believed that it will be less confusing to carry out the calculations using the notation and terminology of the classical

[32] A. C. G. Mitchell and M. W. Zemansky, "Resonance and Radiation in Excited Atoms," Chapter III. Cambridge University Press, 1934.

[33] R. Ladenburg, *Zeit. fur Physik*, **4**, 451 (1921).

theory, and then use equations (52) to (56) inclusive as an aid in the discussion of the values obtained and their significance.

(*b*) *The Frequency and Number of Dispersion Electrons in Saturated Hydrocarbons.*

In view of the fact that excellent data are available for the isomeric heptanes[30, 34] it was decided to calculate the characteristic frequency V_0 and the constant B by solving equation (8) using data for the H_α and H_β lines of hydrogen. The number of dispersion electrons per gram, per molecule and per formula bond were then calculated from B, using equation (9).

The data presented in Table XI show that for all nine isomers the frequency (calculated from the H_α and H_β lines) lies between 2.907×10^{15} and 2.997×10^{15} whereas the number of dispersion electrons per bond varies between 1.02 and 1.09. To see if these results would be duplicated for other spectrum intervals the frequency and number of dispersion electrons were also calculated for the four heptanes representing the extremes of structure and of density, using the $H_\alpha - H_\gamma$ and $H_\beta - H_\gamma$ intervals. The values for V_0 and the number of electrons per bond all fell within the limits obtained for the $H_\alpha - H_\beta$ spectrum interval. The average value for the four extreme heptanes calculated for these spectrum intervals are given at the bottom of Table XI.

The frequency 2.955×10^{15} corresponds to a wave-length of approximately 1015° Angstrom which is so far in the ultra-violet that experimental data are not at present available in the region of the frequency. It may well be that there is no absorption band at exactly this frequency, since V_0 represents what might be called an "integrated" or "averaged" frequency. The fact that this method of calculation provides a method of integrating or averaging the effect of all the absorption bands is from one point of view a definite advantage.

The average number of dispersion electrons per bond for these isomers is 1.066. Since according to our ideas of

[34] G. Edgar and G. Calingaert, *J. Am. Chem. Soc.*, 51, 1546, 1929.

TABLE XI.

Characteristic Frequency and Number of Dispersion Electrons in Isomeric Heptanes Calculated Using Data of Smyth and Stoops.

Compound.	$d\frac{20}{4}$.	$n-\frac{d}{2}$.	V_0.*	B.*	Dispersion Electrons per			Hydrogen Lines Used.
					Gram.	Molecule.	Bond.	
			$\times 10^{15}$	$\times 10^{30}$	$\times 10^{22}$			
3-ethyl pentane	0.6988	1.0443	2.997	8.218	14.6	24.1	1.09	$\alpha-\beta$
2,3-dimethyl pentane	0.6951	1.0444	2.993	8.157	14.6	24.1	1.09	"
3,3-dimethyl pentane	0.6934	1.0444	2.983	8.084	14.5	23.9	1.09	"
2,2,3-trimethyl butane	0.6892	1.0448	2.907	7.619	13.7	22.6	1.02	"
3-methyl hexane	0.6870	1.0452	2.984	8.028	14.5	24.0	1.09	"
normal heptane	0.6836	1.0460	2.969	7.920	14.4	23.8	1.08	"
2-methyl hexane	0.6789	1.0456	2.965	7.838	14.3	23.6	1.07	"
2,4-dimethyl pentane	0.6745	1.0451	2.983	7.870	14.5	23.9	1.09	"
2,2-dimethyl pentane	0.6737	1.0455	2.957	7.727	14.2	23.5	1.07	"
3-ethyl pentane	0.6988	1.0443	2.990	8.179	14.5	24.0	1.09	$\alpha-\gamma$
2,2,3-trimethyl butane	0.6892	1.0448	2.922	7.699	13.9	22.9	1.04	"
n-heptane	0.6836	1.0460	2.919	7.651	13.9	22.9	1.04	"
2,2-dimethyl pentane	0.6737	1.0455	2.947	7.677	14.1	23.4	1.06	"
3-ethyl pentane	0.6988	1.0443	2.979	8.118	14.4	23.8	1.08	$\beta-\gamma$
2,2,3-trimethyl butane	0.6892	1.0448	2.950	7.852	14.1	23.3	1.06	"
n-heptane	0.6836	1.0460	2.983	8.004	14.5	24.0	1.09	"
2,2-dimethyl pentane	0.6737	1.0455	2.930	7.582	14.0	23.1	1.05	"
Average of above four compounds calculated from $\alpha-\beta$, $\alpha-\gamma$ and $\beta-\gamma$	0.6864	1.0451	2.955	7.854	14.19	23.45	1.066	

* V_0 and B calculated from refractive index data.
Values derived from B were calculated to three significant figures only.

valence there are two paired electrons per single bond in hydrocarbons one may write for these isomers

$$f_{ba} = \frac{1.066K}{2.0K} = 0.533, \tag{57}$$

where K = the number of molecules per ml. times the number of formula bonds per molecule. Therefore, f_{ba} the function depending upon the probability of transition and the life of the resonant state is equal to slightly more than $1/2$ for the C – C and C – H bonds in the heptanes. The data in Tables XI and XII indicate that the number of dispersion electrons per bond, and therefore f_{ba}, has very nearly the same value for normal paraffins from C_5 to C_{12} and for cyclohexane and various of its derivatives. This is a verification of the observations of Drude [3] and of Erfle.[40] The latter's values for pentane, hexane and decane are 1.09, 1.11 and 1.13 electrons per bond (see Table XIV).

In view of the relative constancy of the "dispersion electrons" per bond it was decided to assume as a first approximation, that 1.066 electrons per bond ($f_{ba} = 0.533$) is a value characteristic of any C – C or C – H bond in saturated hydrocarbons.

The data in Table XII indicate a slight decrease in characteristic frequency V_0 with increasing molecular weight, but the trend is somewhat concealed by the practical difficulty in solving for B and V_0^2 by the method of simultaneous equations. It was therefore decided to calculate V_0 on the basis of there being 1.066 dispersion electrons per formula bond, using the equation (8) rearranged as follows:

$$V_0 = \sqrt{\frac{(B)}{(n^2 - 1)} + V^2}. \tag{58}$$

For paraffins the following equation may be used for B,

$$B = \frac{dAbe\ 1.066}{M\pi m_0} = \frac{db}{M} \times 5.2091 \times 10^{31}. \tag{59}$$

The data which are given in Table XIII show (1) that there is apparent decrease in frequency with increasing molecular weight in this hydrocarbon series, (2) that calcu-

TABLE XII.

Characteristic Frequency and Number of Dispersion Electrons in Saturated Compounds at 20° C. Calculated from Refractive Indices for the Alpha and Beta Lines of Hydrogen.

Compound.	Density. 20° C.	Refractivity Intercept.	V_0 20° C.	B.	Electron g.	Electron Molecule.	Electron Bond.	Source of Data.
			$\times 10^{15}$	$\times 10^{20}$	$\times 10^{22}$			
Paraffins								
n-Pentane	0.6263	1.0446	2.975	7.243	14.3	17.0	1.06	[35]
n-Hexane	0.65945	1.0454	2.939	7.462	14.0	20.0	1.05	[35]
n-Hexane	0.6603	1.0452	2.926	7.404	13.9	20.2	1.06	[37]
n-Decane	0.7301	1.0470	2.926	8.253	14.0	32.9	1.06	[35]
n-Undecane	0.74025	1.0472	3.000	8.849	14.7	38.3	1.13	[35]
n-Dodecane	0.7489	1.0475	2.915	8.419	13.9	39.3	1.06	[35]
Saturated Cyclics								
Cyclohexane	0.7781	1.0373	2.914	8.409	13.6	18.9	1.05	[36]
Methyl Cyclohexane	0.7707	1.0390	2.894	8.352	13.4	21.7	1.03	[36]
1,2 dimethyl cyclohexane	0.7793	1.0396	2.898	8.500	13.5	25.0	1.04	[37]
1,3 dimethyl cyclohexane	0.7713	1.0396	2.896	8.387	13.6	25.0	1.04	[36]
1 Methyl, 4 Isopropyl cyclohexane	0.7950	1.0412	2.881	8.598	13.4	31.0	1.03	[36]

[35] A. F. Shepard, A. L. Henne and T. Midgely, Jr., Am. Chem. Soc. 19, 48–58 (1931).
[36] A. L. Ward and W. H. Fulweiler, Ind. Eng. Chem., Anal. Edition, 6, 396–400, 1934.
[37] International Critical Tables, McGraw-Hill Co., New York, VII, 34–62, 1930.

TABLE XIII.

Frequency of Dispersion Electrons in Paraffin Hydrocarbons Calculated from Experimental Density and One Refractive Index Measurement Using Empirical Factor of 1.066 Dispersion Electrons per Formula Bond.

No. of Carbon Atoms.	Hydrocarbon.	$d\frac{20}{4}$.	Line Used λ.	n 20°/λ.	V_0. $\times 10^{15}$	R. Int. 20/D.	Source of Refractive Index Data.
5	*n*-pentane	0.62632	H_β	1.36208	2.974	1.0446	35
	n-pentane	0.6262	D	1.3574	2.975	1.0443	23
	2 methyl butane	0.6263	D	1.3577	2.974	1.0446	23
6	*n*-hexane	0.65945	H_β	1.37979	2.961	1.0454	35
	n-hexane	0.6600	D	1.3748	2.963	1.0449	23
	2 methyl pentane	0.6535	D	1.3719	2.962	1.0451	23
7	*n*-heptane	0.6836	H_α	1.38579	2.952	—	30
	n-heptane	0.6839	D	1.3878	2.950	1.0459	23
	n-heptane	0.6836	H_β	1.39248	2.950	1.0460	30
	n-heptane	0.6836	H_γ	1.39648	2.951	—	30
	3 ethyl pentane	0.6984	H_β	1.39839	2.958	1.0445	30
	2,2,3 trimethyl butane	0.6900	H_β	1.39419	2.958	1.0440	30
	2,2 dimethyl pentane	0.6737	H_β	1.38710	2.954	1.0445	30
10	*n*-decane	0.7301	H_β	1.41728	2.933	1.0470	35
13	5 butyl nonane	0.7615	D	1.4273	2.925	1.0466	23
13	4 propyl decane	0.7609	D	1.4272	2.926	1.0468	23
16	3 ethyl tetradecane	0.7789	D	1.4366	2.919	1.0472	23
18	*n*-octadecane	0.7812	D	1.4385	2.914	1.0479	23
20	2 methyl nonadecane	0.7864	D	1.4413	2.910	1.0481	23
	2 ethyl octadecane	0.7928	D	1.4441	2.910	1.0477	23
33	3 penta decyl octadecane	0.8230	D	1.4594	2.903	1.0479	23
35	5 penta decyl henacosane	0.8238	D	1.4598	2.903	1.0479	
x	Hydrogenated rubber	0.8558	D	1.4753	2.894	1.0474	38

[35] H. Staudinger, "Die Hoch Moleckularen Organischen Verbindungen." Julius Springer, Berlin, 1932.

lated on this basis, for the H_β line, the frequencies of the four extreme heptanes lie between 2.952×10^{15} and 2.958×10^{15}, and (3) that the data for normal heptane obtained with the H_α, H_β, H_γ, and D lines all give practically the same frequency when substituted in this formula.

The constance of the frequency over the whole range of heptane isomers accounts for the fact that Newton's equation does represent the change of n with d for this set of isomers. The fact that the frequency appears to decrease in the homologous series as molecular weight increases accounts for the fact that the slope of the refractive index-density curve

for the whole homologous series of paraffins differs from the slope obtained from the simple Newton equation.

The apparent decrease in frequency V_0 as molecular weight increases may be real, or may follow as a consequence of having made the approximation that the C – C and C – H bonds behave similarly in regard to the dispersion of light. Since one can calculate the ratio $\frac{B}{V_0^2 - V^2}$ for high molecular weight and low molecular weight paraffins it would be possible to write, and at least tentatively solve, an equation with separate terms for the C – C and C – H linkages, making due allowances for the effect of carbon and hydrogen ratio. The authors feel that a mass of data all obtained in one laboratory and for a very wide range of molecular weights, should be available before any such calculation is attempted.

If the decrease in frequency V_0 with increasing molecular weight is actually real, it is perhaps caused by higher internal pressure in the higher molecular weight compounds. The high density, low compressibility and low coefficient of expansion of the higher molecular weight members of the paraffin homologous series all indicate, qualitatively at least, higher internal pressure with higher molecular weight.[39]

(*c*) *The Frequency and Number of Dispersion Electrons in Olefins and Aromatics.*

Table XIV gives the data of Erfle [40] for $p\frac{e}{m_0}$ and the value (the number of dispersion electrons per molecule) calculated from these data using the modern value for e/m_0. If the number of dispersion electrons per bond (column 6) is calculated on the basis of the total number of bonds in the molecule (column 4) it is seen that rather low values are obtained for the non-cycle unsaturates and very low values are obtained for the aromatics. If one assumes tentatively that only the single bonds (column 5) affect the dispersion in the visible spectrum, the ratio of dispersion electrons to single bonds

[39] T. W. Richards, *Chemical Reviews*, **2**, pp. 315–348 (1926); J. FRANKLIN INST., **198**, pp. 1–27 (1924).

TABLE XIV.

*Dispersion Electrons per Bond Calculated from Data * of Erfle.*[40]

Hydrocarbon.	$p\frac{e}{m_0}\times 10^7$.	p.†	Formula Bond.		Dispersion Electrons.	
			Total.	Single.	Per Bond.	Per Single Bond.
Pentane	30.98	17.5	16	16	1.09	1.09
Hexane	37.29	21.1	19	19	1.11	1.11
Decane	62.0	35.0	31	31	1.13	1.13
Amylene	22.92	13.0	15	13	0.86	1.00
Hexylene	28.04	15.9	18	16	0.88	0.99
Octylene	38.9	22.0	24	22	0.92	1.00
Decylene	49.9	28.2	30	28	0.94	1.01
Diallyl	24.6	13.9	17	13	0.82	1.07
Heptadiene	32.98	18.6	20	16	0.93	1.16
Dipropargyl	19.20	10.8	15	9	0.72	1.20
Benzene	16.7	9.44	15	9	0.62	1.03
Toluene	20.78	11.7	18	12	0.65	0.98
Ethyl benzene	25.04	14.2	21	15	0.67	0.95
O-xylene	24.23	13.7	21	15	0.65	0.91
m-xylene	24.09	13.7	21	15	0.65	0.91
p-xylene	23.10	13.1	21	15	0.62	0.97
Propyl benzene	29.5	16.7	24	18	0.70	0.93
Iso propyl benzene	29.2	16.5	24	18	0.69	0.92
Mesitylene	28.98	16.3	24	18	0.68	0.91
Psuedo cymene	27.84	15.7	24	18	0.66	0.87
Iso butyl benzene	34.40	19.4	27	21	0.72	0.93
Cymene	34.43	19.5	27	21	0.72	0.93
Naphthane	20.92	11.8	24	14	0.50	0.85
Tetra hydro benzene	27.3	15.4	17	15	0.91	1.03
Di hydro benzene	19.6	11.1	16	12	0.69	0.92
Hexahydro naphthalene	32.89	18.6	27	23	0.69	0.81
Phenyl acetylene	18.36	10.4	19	10	0.55	1.04

* Notations used p = number of dispersion electrons per molecule

$\frac{e}{m_0}$ = the ratio of the charge to the mass of the electron in electromagnetic units.

† Calculated from $p\,e/m_0$ using $e/m_0 = 1.769\cdot 10^7$.

[40] H. Erfle, *Annalen der Physik*, **24**, 672–708, 1907; *Zeit. fur Physik Chemie*, **61**, 399–421, 1908.

(column 7) is found to be more constant and approximately equal to unity.

Table XV gives modern data for a few aromatic and other unsaturated compounds. Here again the number of "dis-

TABLE XV.

Characteristic Frequencies and Number of Dispersion Electrons for a Few Aromatic and Unsaturated Compounds.

Compound.	Density 20° C.	Refractivity Intercept.	V_0.	B.	Electrons per				Source.
					Gram.	Mol.	Bond.	Single Bonds only.	
			$\times 10^{15}$	$\times 10^{30}$	$\times 10^{22}$				
Benzene	0.8791	1.0619	2.152	5.484	7.74	9.95	.66	1.10	37
Toluene	0.8677	1.0628	2.190	5.626	8.05	12.2	.68	1.02	38
1 Methyl 4 Isopropyl Benzene	0.8582	1.0615	2.273	5.996	8.40	19.2	.70	1.01	38
1,2,4 dimethyl ethyl benzene	0.8792	1.0650	2.265	6.158	8.70	19.2	.70	1.01	38
1 Methyl, 4 Isopropyl dihydrobenzene	0.8502	1.0564	2.403	6.592	9.63	21.6	.83	0.98	38
1 Methyl, 4 Isopropyl tetrahydrobenzene	0.8098	1.0535	2.703	7.939	12.2	27.7	.96	1.03	38
Decene	0.7418	1.0546	2.739	7.476	12.5	29.0	.97	1.04	38

persion electrons" *per single bond* remains quite constant. The frequency of vibration V_0 is always lower in the unsaturated compounds than in the saturated.

The tentative assumption that only the electrons in single bonds are directly concerned with dispersion in the visible spectrum means that the fraction $f_{II_{ba}}/[(V_{II_{ba}})^2 - V^2]$ in equation (56) is nearly zero. This may mean either (*A*) that the probability of transition is very small, and that $f_{II_{ba}}$ is therefore very small, or (*B*) that the characteristic frequency $V_{II_{ba}}$ is very large, i.e., that the "dispersion absorption band" for unsaturated linkages themselves lies in the extreme ultraviolet. On the other hand, the absorption band calculated for the electrons which do affect dispersion in the visible, is nearer the visible spectrum for unsaturated compounds than for saturated compounds.

The data in Tables XIV and XV give considerable support to the idea that only the electrons in single bonds are directly connected with dispersion, and it is probable that a further investigation will reveal the true reason for this effect. It is also hoped that a continuation of this study will lead to a better understanding of both conjugation and of the properties of the benzene ring.

VII. ELECTRONIC INTERPRETATION OF REFRACTIVITY INTERCEPT.

(*a*) *Comparison of Paraffins with Naphthenes*

In view of the well known marked similarity between the saturated cyclic and paraffinic hydrocarbons, it is of interest to determine, if possible, why ring closure results in the rather significant decrease in average refractivity intercept from 1.0461 for paraffins to 1.0400 for naphthenes.

The preceding discussion has shown that the refractive index and density data for paraffinic hydrocarbons can be very satisfactorily correlated by using equations (8) and (14). It is, therefore, reasonable to use equation (8) as a tool in trying to find the fundamental reason for the difference in refractivity intercept between the paraffins and saturated cyclics.

Assume that a paraffin and naphthene each having a density of 0.800 g./ml. and refractivity intercepts of 1.0461

and 1.0400, respectively, are to be compared. These refractivity intercepts are representative of each hydrocarbon type as shown in the first part of this paper (1). The refractive index of the paraffin will be 1.4461 and of the naphthene 1.4400, and $n^2 - 1$ will be 1.0912 and 1.0736 for the two compounds, respectively. The ratio $\frac{B}{V_0^2 - V^2}$ for naphthenes of this density is therefore 1.6 per cent. lower than for the paraffin of the same density.

On the basis of the data in Tables XII and XIII, it is clear that for the paraffin homologous series the apparent frequency decreases with increasing molecular weight and, therefore, approximately with increasing density. In view of the present state of these data it appears reasonable to assume as an approximation that V_0^2 for the paraffin and V_0^2 for the naphthene of the same density are equal.

Therefore, if $n^2 - 1$ for the naphthene is 1.6 per cent. less than for the paraffin, B must be 1.6 per cent. less, and since the naphthene and paraffin have the same density the number of electrons per gram will be 1.6 per cent. less for the naphthene than for the paraffin. The number of electrons per gram for a paraffin of 0.800 density may be taken as 14.0×10^{22}, therefore subtracting 1.6 per cent. gives 13.78×10^{22} electrons per gram for the naphthene.

In Table XII the values for electrons per gram for naphthenes are 13.4 to 13.6×10^{22}, which values are 0.2 to 0.4×10^{22} too low. These figures however correspond to values of electrons per bond of 1.03 to 1.05, which may be low due to the lack of precision in calculating B by solving two simultaneous equations. If one assumes that there should be 1.066 dispersion electrons per bond in naphthenes as well as in paraffin, then all naphthenes should have 13.82×10^{22} electrons per gram. This value agrees very well with the value 13.78×10^{22} electrons per gram which was calculated for a naphthene of 0.800 density from the refractivity intercepts for paraffins and naphthenes given in Table V in the first part of this paper.[1]

On the basis of the present data it therefore appears that the difference in refractivity intercept of paraffins and naphthenes is primarily due to the fact that there are approxi-

mately 13.8×10^{22} dispersion electrons per gram in naphthenes, and 14.0 to 14.3×10^{22} dispersion electrons per gram in paraffins, the frequency of these electrons and the number per bond being essentially the same, for a given density, in both homologous series. According to this point of view the refractivity intercepts of paraffins and naphthenes are closely related to their carbon and hydrogen ratio, since the number of bonds per gram decreases as the proportion of hydrogen decreases. The situation at best is complex and the interpretation here given is not intended to be final.

(*b*) *Comparison of Aromatics and Olefins with Naphthenes.*

Assume that a hypothetical naphthene and aromatic each having a density of 0.900 g./ml. and refractivity intercepts of 1.0400 and 1.0627, respectively, are to be compared. These refractivity intercepts are representative of each hydrocarbon type as shown in Table V of reference (1). The refractive index of the naphthene will be 1.4900, and of the aromatic 1.5127, and $n^2 - 1$ will be 1.2200 and 1.2883 respectively. The ratio $\frac{B}{V_0^2 - V^2}$ for aromatics of this density will therefore be 5.6 per cent. higher than that for the naphthene of the same density.

One may estimate from the data in Table XII, and the value 13.8×10^{22} dispersion electrons per gram, that V_0^2 and B for a naphthene of 0.9000 density will be approximately 8.41×10^{30} and 10.0×10^{30} respectively. For an aromatic of 0.900 density V_0^2 is 4.63×10^{30}. The term $V_0^2 - V^2$ for the aromatic material is therefore approximately 45 per cent. less than for the naphthenic material. Since $B = (n^2 - 1) \times (V_0^2 - V^2)$ the B term for the aromatic compound should be 1.056×0.550 of B for the naphthenic compound. Therefore B for the aromatic compound should be $0.58 \times 10.0 \times 10^{30} = 5.8 \times 10^{30}$, which corresponds to 7.2×10^{22} electrons per milliliter or 8.0×10^{22} electrons per gram. This is reasonably well in accord with the values calculated for benzene and toluene as given in Table XV.

One may say therefore that both the number and frequency of the dispersion electrons are both much less in aromatic compounds than in naphthenic compounds, but

that V_0^2 decreases more rapidly than B, and therefore the net effect is a high refractive index for a given density in the case of the aromatics.

Direct comparison of the data for cyclohexane and benzene leads to the same conclusion as does the comparison just made on the basis of compounds of similar density. Benzene, and the aromatic hydrocarbons in general, form a special class of unsaturated compounds in which there are three conjugated double bonds in a six membered ring. The transition from the saturated cyclohexane ring to the benzene ring may be followed step by step by comparing 1 methyl 4 isopropyl cyclohexane in Table XII with the corresponding compounds having 1, 2 and 3 double bonds in the ring as given in Table XV. These data together with the data for decene lead one to conclude that all compounds containing double bonds have relatively high refractive indices and intercepts for the same reason, namely that the decrement for V_0^2 is greater than the decrement for B when a double bond is introduced into the molecular structure.

VIII. ELECTRONIC INTERPRETATION OF THE NEWTON SPECIFIC REFRACTION EQUATION.

Newton was gratified to find that his specific refraction equation, $(n^2 - 1)/d$ = constant, gave so nearly a universal constant as is shown in column 5 of Table I in the first part of this paper.[1] Although he investigated materials ranging in density from air to diamond, the minimum constant found was 0.398 for "pseudo topaz" and the maximum 1.456 for diamond. These observations may now be interpreted in terms of equations (8), (14) and (16). Apparently the relative constancy of the Newton constant means that the product $\frac{bk}{M}\frac{(1)}{(V_0^2 - V^2)}$ or $\frac{p}{M}\frac{(1)}{(V_0^2 - V^2)}$ is approximately constant for a wide range of materials. Furthermore, it seems probable that the ratio of dispersion electrons per ml. (p) to the molecular or formula weight (M) does not vary over a very wide range, and that V_0^2 also fluctuates within relatively narrow limits. Within the range of variations which does occur, there are however, significant trends well worth study.

In the case of the isomeric heptanes both p/M and V_0^2

remain constant within narrow limits. Therefore, the Newton equation accurately represents the data for these compounds as shown in Table III and Fig. 1 of reference 1.

The constancy of the Newton specific refraction for groups of hydrocarbon isomers of course means that molecular refractions calculated by the original molecular refraction equation of Berthelot [41] will be more constant for groups

$$(60) \qquad \text{Molecular Refraction} = \text{Mol. Wt.}\left[\frac{n^2 - 1}{d}\right]$$

of hydrocarbon isomers than the molecular refraction calculated by the Lorentz-Lorenz equation. The authors are inclined to doubt the fundamental value of the atomic additivity approach to the problem of refraction, but if atomic constants are to be used it is believed that they should be based on data obtained at 20° C. and should be calculated for the Newton-Berthelot molecular refraction equation.

The deviations from the Newton equation which occur when temperature is changed may be conveniently interpreted as due to changes in V_0^2. This will be discussed in the next sections.

IX. THE ELECTRONIC INTERPRETATION OF THE EYKMAN EQUATION FOR THE EFFECT OF TEMPERATURE ON REFRACTIVE INDEX.

The effect of temperature on density and refractive index is more accurately represented by the Eykman [1, 13, 22, 23] equation $(n^2 - 1)/(n - 0.4)d$ = constant than by the Lorentz-Lorenz specific refraction formula so generally used. This was shown in Table IV and has been recognized by most experts in this field, who have nevertheless preferred to use the Lorentz-Lorenz equation because of its theoretical derivation. For example, Nernst [14] says "Small variations of the expression $\frac{n^2 - 1}{n^2 + 2}$ from proportionately with the density on change of temperature have been found which, however, exceed errors of observation. Eykman suggested from a large and varied collection of observations the expression $\frac{(n^2 - 1)}{(n + 0.4)}$ as expressing this proportionality more completely,

[41] Berthelot, *Ann. Chim. Phys.*, (3), **48**, 342 (1856).

but as this has no theoretical foundation it can only be considered as an interpolation formula."

Since it has been shown in this paper that the theoretical foundation of the Lorentz-Lorenz formula is unsound, it is of interest to see if a modified form of the Sellmeier-Drude type of equation can be obtained which will accurately express the relation between refractive index and density with changing temperature. Table XVI presents data of Eykman for a few

TABLE XVI.

Characteristic Frequency and Number of Dispersion Electrons in Saturated Compounds at Temperatures Other than 20° C.

Data of Eykman.[13]

Substance.	Temp. °C.	d_t.	H.	H_a.	V_0.	B.	Electrons per		
							Gram.	Mol.	Bond.
					$\times 10^{15}$	$\times 10^{20}$	$\times 10^{22}$		
n-Hexane.....	14	0.6652	1.38365	1.37725	3.015	7.964	14.8	21.0	1.10
"	44.95	0.6365	1.36635	1.36024	3.040	8.611	15.0	21.2	1.12
Paraffin $C_{19}H_{42}$.	38.3	0.7762	1.44095	1.43331	2.938	8.881	14.2	66.0	1.08
" " .	136	0.7110	1.40142	1.39459	2.970	8.135	14.2	66.0	1.08
Naphthene *...	15.5	0.8522	1.47372	1.46547	2.918	9.534	13.9	—	—
" .	133.6	0.7744	1.42774	1.42031	2.938	8.572	14.1	—	—

* Eykman does not give the molecular weight or formula of this compound.

hydrocarbons over a relatively wide temperature range, and the values of V_0 and B calculated from these data. The number of dispersion electrons per bond remains so nearly constant that it again seems justifiable to assume that over the temperature interval studied f_{ba} may be considered constant, i.e., that the probability of transition is not affected by temperature within these limits.

In Table XVII data are shown for $\Delta V_0/\Delta t$ calculated on the basis of B being proportional to density. The frequency of vibration of the dispersion electrons in this table increases slightly with increasing temperature. Furthermore, there is shown to be a constant relation between $\Delta V_0/\Delta t$ and $\Delta d/\Delta t$ for saturated hydrocarbons. This opens the way for writing a modified form of the Sellmeier-Drude specific refraction equation which will express the change of refractive index with temperature, provided the change of density with

TABLE XVII.

Effect of Temperature on Frequency of Absorbing Electrons on Assumption that B is Proportional to Density for Any One Compound.

Substance.	$d\,\frac{20}{4}$.	Temp. Range °C.	ΔV_0.	$\Delta V_0/\Delta t = x$.	$\Delta d/\Delta t = y$.	x/y.
			$\times 10^{13}$	$\times 10^{11}$	$\times 10^{-4}$	$\times 10^{15}$
n-Hexane *	0.6597	14–44.95	1.34	+4.34	−9.25	−.470
Cyclohexane †	0.7781	20–70	1.98	+3.96	−8.70	−.455
n-Decane †	0.7308	20–70	1.80	+3.60	−7.65	−.470
n-Eicosane *	0.7884 ‡	38.3–.36	3.18	+3.25	−6.67	−.485
Naphthene *	0.8491	15.5–133.6	3.60	+3.05	−6.59	−.462
Average for Saturated Cpds.						−.47
Benzene †	0.8791	20–70	1.91	3.80	10.8	−.35

* Experimental data of Eykman.

† Density change calculated from equations given in I.C.T. Vol. III, p. 29 and refractive index change calculated with Eykman's equation.

‡ Hypothetical density if eicosane would remain liquid at 20° C.

temperature is known. If one uses the subscript 1 to indicate 20° C. and subscript 2 to indicate any other temperature, then

$$N_2 = \frac{(d_2)}{(d_1)} N_1, \tag{61}$$

$$V_{02} = (V_{01} + \phi), \text{ and} \tag{62}$$

$$\phi = + \frac{(\Delta V_0)}{(\Delta t)} (t_2 - t_1), \tag{63}$$

$$\frac{\Delta V_0}{\Delta t} = 0.47 \times 10^{15} \frac{\Delta d}{\Delta t}, \tag{64}$$

$$\phi = 0.47 \times 10^{15} \Delta d. \tag{65}$$

Therefore writing equation (8) for temperature t_2 and substituting equations (61) and (62) one obtains

$$\frac{n^2 - 1}{d_2} = \frac{B_1}{d_1(V_{01} + \phi)^2 - V^2}, \tag{66}$$

in which ϕ may be evaluated by means of equation (65) and B_1 may be obtained from the relation $B_1 = Ne^2/\pi m_0$.

Equation (66), though quite different in form from the Eykman equation, is found to yield values for n and d very

nearly identical with those obtained from the Eykman equation. It was checked for decane by taking the value $B_1 = 8.253 \times 10^3$ and $V_0 = 2.926 \times 10^{15}$ at 20° C. from Table XII and calculating the n corresponding to densities from 0.73 to 0.62. Taking d at 20° C. = 0.7301 and at 45.3° C. = 0.7112 one obtains on calculation 1.40075 for the refractive index at 45.3° C. Midgely, et al.[35] obtained 1.40047 for decane at this temperature. The check with experimental data is good within 3 in the fourth decimal place. To check the agreement of the Eykman form of equation and equation (66) the Eykman constant was calculated for decane using $d\frac{20}{4} = 0.7301$ and $n\frac{20}{4} = 1.4120$. Values of n were then assumed and d calculated by the Eykman equation. Similarly using the values of B_1 and N_0 for decane from Table XII to complete equation (66) it was possible to assume values of d_2 and calculate n_2. The curve expressing the change of d and n with temperature obtained in these two ways check within approximately ± 2 in the fourth place.

This type of formulation appears to be equivalent to the Eykman equation and for saturated hydrocarbons, at least, it appears that ϕ may be evaluated with sufficient accuracy using equations (63) to (65). It is shown in Table XVII that equations (64) and (65) do not hold for benzene; therefore, until further calculations have been made these equations should not be used for anything but saturated hydrocarbons in the liquid state.

In certain cases it is desirable to eliminate B_1 which leads to

$$\frac{n_2^2 - 1}{n_1^2 - 1} = \frac{d_2}{d_1} \frac{(V_0^2 - V^2)}{[(V_0 + \phi)^2 - V^2]}. \tag{67}$$

Furthermore, Eykman has shown that $(n^2 - 1)/(n + 0.4)d$ = constant. Therefore one may divide both sides of equation (66) by $n_2 + 0.4$, hence

$$\left[\frac{n_2^2 - 1}{n_2 + 0.4}\right]\frac{1}{d_2} = \frac{B_1}{(n_2 + 0.4)d_1[(V_0 + \phi)^2 - V^2]} \tag{68}$$

$$\text{constant} = C.$$

Therefore, the constant in the Eykman equation is given by the equation

(69) Eykman Constant

$$= \frac{N_1 e^2}{(n_2 + 0.4) d_1 \pi m_0 [(V_{0_1} + \phi)^2 - V^2]} = C$$

Now if the refractive index (n_1) and density (d_1) for one temperature are available, C can be calculated. In the case of paraffins B_1, can be calculated from equation (59), ϕ can be calculated from equation (65) if the coefficient of expansion is known, and V_0 can be estimated from d_1 and the data in Table XIII. Therefore, for paraffins the constants in equation (66) can be evaluated from a small amount of experimental data. It is to be expected that after further collection and correlation of data it will be possible to evaluate the constants in these equations for any type of organic compound.

The theoretical background of equation (66), which gives values in close agreement with the Eykman equation should eliminate the objection to the use of the latter admittedly empirical but also admittedly valid equation.

X. SUMMARY AND CONCLUSION.

1. The number and frequency of vibration of dispersion electrons in various classes of hydrocarbons have been calculated in order to obtain a better understanding of the linear relation between refractive index and density upon which the refractivity intercept is based. The Sellmeier-Drude equation was used in making these calculations since it was shown that the derivation of this equation is apparently sound and that it can be justified empirically.

2. Careful investigation revealed that the theoretical derivations of the Lorentz-Lorenz and Clausius-Mosotti equations are unsound, and that neither the $\frac{n^2 - 1}{n^2 + 2}$ nor the $\frac{\epsilon - 1}{\epsilon + 2}$ form of equation can be justified on an empirical basis, since they are incapable of accurately correlating the available experimental data for the effect of temperature and pressure on non-polar liquids. The fact that the Lorentz-Lorenz equation does yield a constant with certain data for gases is

not necessarily proof of its validity, since when the refractive index does not differ greatly from 1.0 a variety of equations can be written which will adequately represent such data.

3. Calculations using the Sellmeier-Drude type of equation lead to the following conclusions:

(*a*) That there is *one* dispersion electron per formula bond (either C − C or C − H) in saturated hydrocarbons;

(*b*) That in unsaturated hydrocarbons there is less than one dispersion electron per bond if all formula bonds are considered, but if only single bonds are considered there is again 1 dispersion electron per bond.

(*c*) That for the three most important classes of hydrocarbons the number of dispersion electrons per gram are as follows: paraffins 14.0×10^{22}; naphthenes 13.8×10^{22} and aromatics 8.0×10^{22}. The characteristic frequencies of vibration are approximately as follows: paraffins 2.95×10^{15}, naphthenes 2.90×10^{15} and aromatics 2.2×10^{15}.

4. The refractivity intercepts of naphthenes are therefore lower than the refractivity intercepts of paraffins, because, first, there are fewer electrons per gram in the former than in the latter, and, second, because the frequency of vibration of these dispersion electrons is almost the same in both classes of compounds. The refractivity intercepts of aromatic compounds are higher than for paraffinic or naphthenic compounds, since the decrease in frequency of vibration of the dispersion electrons raises the refractive index more than the decrease in their number lowers the refractive index.

5. The above data may be reinterpreted in the light of wave mechanics as follows:

(*a*) Carbon-carbon and carbon-hydrogen bonds are generally believed to involve a pair of electrons. Calculations from dispersion data indicate *one* dispersion electron per bond. This means that the "*f*" coefficient depending on the probability of transition of the valence electrons is approximately 0.5 in saturated hydrocarbons.

(*b*) The data indicating that the electrons in double bonds do not contribute to the *number* of dispersion electrons

may mean either that the "f" coefficient depending upon the probability of transition is practically zero, or that the characteristic absorption band for the double bond is so far in the ultraviolet that it has no influence on dispersion in the visible spectrum.

6. The systematic study of the effect of pressure and temperature on the relation between density and either refractive index or dielectric constant has shown that the Eykman type of equation $\frac{n^2 - 1}{n + 0.4}\frac{1}{d} = \text{constant}$, and $\frac{\epsilon - 1}{0.4 + \sqrt{\epsilon}}\frac{1}{d} = \text{constant}$, represents the effect of temperature or pressure within the accuracy of most of the experimental data.

7. The change in frequency of vibration of the dispersion electrons with change in temperature has been calculated on the assumption that the *number* of dispersion electrons is independent of temperature. The change in frequency thus calculated is, for saturated hydrocarbons at least, a linear function of the change in density. Introduction of this temperature coefficient of the frequency of vibration into the Sellmeier-Drude dispersion equation yields an equation which represents the change of refractive index with temperature as accurately as does the empirical Eykman equation, furthermore the constant in the Eykman equation has been evaluated.

8. It is concluded:

(*a*) That the linear relation between refractive index and density in each homologous series is a direct consequence of the approximate constancy in each homologous series of the number of dispersion electrons per gram and of their frequency.

(*b*) That the refractivity intercept $n - d/2$ is a very useful constant for differentiating naphthenes from paraffins and aromatics, for identifying homologous series, and for analyzing certain binary and tertiary mixtures of pure or approximately pure compounds.

(*c*) That the Newton specific refraction equation should be used for the relation between the density and refractive index, at constant temperature and pressure, for groups

of isomeric paraffins. If molecular refractions are to be calculated in terms of approximate atomic constants these constants should be worked out for the Newton-Berthelot equation rather than the Lorentz-Lorenz type of equation.

(*d*) That the equations in the Eykman form should be used for the effect of temperature or pressure on the relation between density and either refractive index or dielectric constant.

(*e*) That the Sellmeier-Drude dispersion equation should be used for the correlation of dispersion data for hydrocarbons.

(*f*) That equations in the Lorentz-Lorenz and Clausius-Mosotti forms should not be used except as representing very approximate empirical relations.

THE MICROCHEMICAL LABORATORY OF THE BIOCHEMICAL RESEARCH FOUNDATION.

A TECHNICAL REPORT OF ITS CONSTRUCTION AND FUNCTION.*

BY

HERBERT K. ALBER and JOSEF HARAND.

A. INTRODUCTION.

The importance of microchemical methods in the field of applied chemistry is generally recognized today. Therefore, in the course of its development the Biochemical Research Foundation decided to establish a special group for the purpose of doing all the microanalytical work for its other departments. At the beginning, there were no detailed plans for the relation of the microchemical department to the other groups of the Institute in regard to coöperation and to research work. A few fundamental lines, however, could be drawn immediately according to the following general trends:

1. The microchemical department was to perform all the analytical work on new compounds or isolated products resulting from the research work of the different groups, insofar as the methods were not connected directly with the problem. The need for microchemical methods does not arise from the availability of small amounts of material only (often less than 20 mg.), but also from the saving of time in carrying out the methods. These advantages of time saving are considered to be important in cases where the different steps of a reaction should be followed closely. The completeness, or yield at a given moment may be determined; the procedure can be stopped or changed if conditions are unfavorable as indicated by the analytical results. Sometimes, the microanalytical methods permit obtaining results in a much *simpler* way, or in a more *accurate* way, than on a macro scale; the control of purities of reagents, identification of materials, their analysis and the control of their stability

* From the Biochemical Research Foundation of The Franklin Institute (Dr. Ellice McDonald, Director), Philadelphia, Pa.

after use in different procedures or apparatus fall into the proposed program.

It was expected that most of the problems would be derived from work on organic or biochemical problems, so that the need of organic analytical procedures arose immediately. Nevertheless, it was safe to consider from the beginning qualitative inorganic and also quantitative inorganic procedures to a certain extent.

2. Besides being occupied mainly with analytical work, the microchemical group was to function in the role of advisory group for analytical problems in general, with special emphasis on qualitative organic elementary analysis.

3. The fundamental postulate of the Biochemical Research Foundation, that the members of the staff contribute original research work, was not to be excluded. Research was to be carried on not only in the special field of pure microchemistry, as it appeared related to different incoming problems, but also, if possible, along the lines of the Institute in the biochemical field.

Adopting these points as the fundamental basis for the first period of the work, the microchemical group considered the following methods and equipment as necessary and sufficient for satisfactory functioning:

a. Qualitative Organic Elementary Analysis.—Methods according to the work of Emich, Feigl, Rosenthaler, and others, and newer modifications as developed by Alber, are proposed. Following one of the general schemes, e.g., of Staudinger, Kamm, or Shriner and Fuson, the next step in the identification of organic compounds is the determination of the physical constants. The most important of these are the boiling point (capillary method of Emich), refractive index (Beckeline test, Abbe refractometer, "schlieren"-method of Emich and co-workers), viscosity (apparatus of Mouquin and Alber), specific gravity ("schlieren"-method, specific gravity pipettes of Alber for 20 to 50 cmm., or the pipettes of Pregl for larger amounts, and for solids, the floating method), melting point (capillary method, hot stage of Kofler for single crystals), optical structure and properties (identification of crystals by the methods of Behrens, Chamot and Mason, Emich, A. Kofler, Mayerhofer, etc.). The solubility tests can be easily

performed on slides or in centrifuge cones. The confirmatory tests for the purified and isolated organic compounds include the spot test technique of Feigl, formation of crystalline derivatives on slides and their observation under the microscope as mentioned above, and the preparation of special derivatives for the determination of their physical constants. For the last of these procedures the capillary techniques of Emich-Fuchs, Benedetti-Pichler, and others are applied in their original form or modified according to experiences in systematic studies by Alber.

b. Qualitative Inorganic Analysis.—The goal for this type of determination is not only the identification of the inorganic substances, but also the semi-quantitative estimation of the constituents of the sample starting with about 1 mg. Methods for the latter have been developed just recently by Benedetti-Pichler and Spikes; they have been modified for very small amounts of material (on the gamma scale) by Alber and Rodden. Otherwise the standard procedures of Behrens, Chamot and Mason, Emich, Benedetti-Pichler, Feigl are applicable and newer modifications will be used as they appear in the literature. The determination of physical constants can be carried out in the same way as mentioned under *a* for organic substances.

c. Quantitative Elementary Analysis of Organic Substances.—This phase is considered to be the most important and is expected to be routine work. The wellknown standard procedures of Pregl, Friedrich, Niederl, and others, are more or less designed for "pure" samples, e.g., as obtained in the final steps of a reaction for the structure proof and identification. However, in biochemical work, the obtaining of highly purified material is very difficult, sometimes impossible; therefore the apparatus must be adaptable for modifications and improvements which through experience will have to be developed for the presence of impurities that would vitiate the ultimate results. Sufficient accuracy and readiness in urgent cases are made possible through the permanent arrangement of the most important apparatus and procedures for the organic elementary analysis, such as for residues, ash, carbon and hydrogen, nitrogen by the Dumas method, nitrogen by the Kjeldahl method, halogens, sulfur, phosphorus, arsenic, and metals deposited by electrolysis.

Apparatus of a more special nature are provided for the determination of organic groups such as methoxyl, ethoxyl, methylimide, methylsulfide, carboxyl, and molecular weights of solids according to Pregl-Rast, molecular weights of liquids according to Niederl-Trautz-Plentl, and finally by the osmotic pressure method of Barger-Friedrich.

Determinations of infrequent occurrence, such as hydrogenation, determination of active hydrogen, acetyl or benzoyl groups, double linkages, saponification, etc., are not included in the program at the present time.

d. Quantitative Analysis of Inorganic Substances.—Microchemical procedures are known for this group of methods, but no general scheme has been worked out and no book has been written on this subject. The only guide is the experience obtained from teaching and working on the *general techniques* in gravimetric microanalysis (filterstick method of Emich for separating and drying the precipitates at low temperatures or up to 1100° C., filter tube method of Pregl, micro electrolysis of Clarke and Hermance, centrifugal analysis), in volumetric analysis (titration according to general rules established by Pregl, and different modifications) and in colorimetric analysis. The last of these is not provided for especially in micro form, since enough colorimeters are available in the Institute, as e.g., the very suitable Lange photoelectric colorimeter.

e. Microchemical Balances.—The Kuhlmann microchemical balance is considered to be the best instrument on the market at the present time. Many literature references, nevertheless, are available on the important influence of the surroundings of the balance on the utmost accuracy and sensitivity obtainable with this precision instrument. As the final results are dependent upon the accuracy of the weighings it is important that the set-up of the microchemical balances be planned with all known difficulties in mind. A detailed description is given under the heading of "Balance Room," page 748.

f. Microchemical Literature.—Microchemistry is a rather new field in science and a few more or less special handbooks have appeared. Many new developments accumulate in the comparatively extensive literature, which must be easily accessible in order to save time. Besides several handbooks, the journals dealing with microanalytical procedures, such as

"Mikrochemie" and the Analytical Edition of "Industrial and Engineering Chemistry" have been made available by the library of the Institute. Considerable effort will be placed on increasing the number of microchemical papers in the extensive reprint collection of the Institute.

B. SELECTING EQUIPMENT.

After surveying the scope and requirements of the laboratory the next step was the purchasing of the equipment. Apparatus of the necessary accurate dimensions for this type of work have been rather difficult to obtain in this country, hence much of the equipment had to be ordered from abroad, where microchemistry had an earlier start. Wherever possible apparatus was obtained from the few American manufacturing houses interested in microchemistry, or constructed according to drawings supplied to the mechanics and glass-blower of the Bartol Research Foundation of the Franklin Institute. It is believed that the equipment finally obtained is of a very high grade of workmanship and of the best durability.

The actual arrangement of the above mentioned apparatus took more time than expected, since the rooms assigned for this purpose had not been used previously for a *chemical* laboratory. The microanalytical group decided to fit everything into the available space. Equipment of such special type must be set up under the best conditions of distribution, accessibility, readiness, and convenience to the worker. The last mentioned point is very important for the microanalyst in order to avoid unnecessary strain, which easily results from the finer type of analytical work.

With the exception of the microscope table, which fortunately fitted exactly into the final lay-out, all work benches, tables, special equipment such as glass blowing table, titration table, shelves, etc., have been designed by the group and worked out with the coöperation of Mr. Van Horn of Metzger and Company, Philadelphia. It should be mentioned that much helpful and logical advice came from this source.

Following is a rather detailed description of the microchemical laboratory as it appears after about six months of

actual operation. To the layman as well as to the chemist, who does not have experience in handling such small amounts of material as used in milligram and gamma procedures, many of the following details may seem superfluous. But it should be kept in mind, that everything has been based on the wide experience of the two authors gained in setting up four different microchemical laboratories, and suggestions found in the literature. It is hoped that this report will be helpful to other workers who may be concerned with the same problem of starting a new microchemical laboratory. It must be mentioned that some of the features incorporated into the final selection have been adopted from other laboratories where experience has found them practical. The equipment and space-saving features of the Microchemical Department of the Bell Telephone Laboratories in New York have served in several respects as a guide in the planning of the Institute's Microchemical Laboratory.

C. DESCRIPTION OF THE LABORATORY.

Figure 1 shows the plan of the laboratory, which in general, is divided into five sections:

Room A is for the preparative work, decomposition of samples, and all manipulations which require a hood, in order to avoid corrosion of the finer apparatus, such as the microchemical balances, etc.

Room B, a room for microscopical investigations, serves at the same time as an office and reference room. It is intended to carry out in this room all the inorganic and organic qualitative analyses, such as spot tests, centrifuge cone technique, capillary work, all the finer mechanical separations under the microscope, and techniques connected with chemical microscopy.

Room C is mainly used for drying samples in vacuum, filtration procedures in quantitative work, all manipulations necessitating the use of a suction device, and micro titrations.

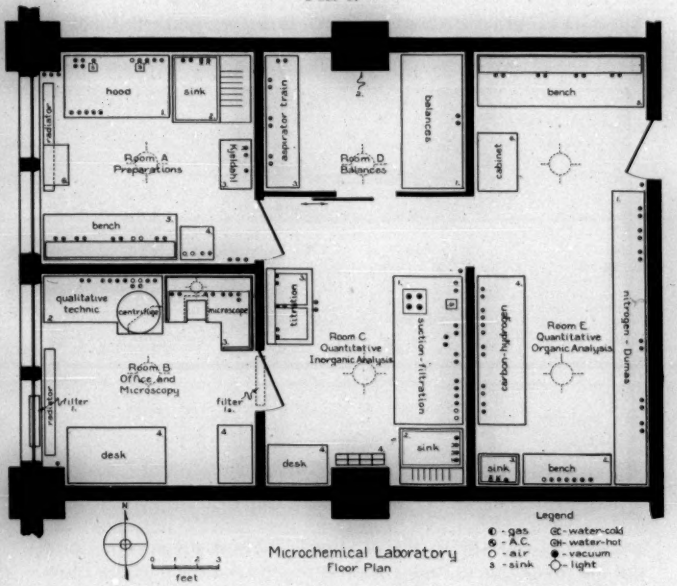
Room D is separated from room C by a plywood wall only and serves as a balance room for all microchemical weighings.

Room E is equipped for the elementary organic quantitative microanalysis, electrolytic procedures, and has space for special apparatus which can be set up if needed.

Room A. Hood Room and Preparation Room.—This room is furnished with the following items (the numbers in this and all the other descriptions refer to the numbers in Fig. 1):

1. The *hood* (Fig. 2), $5' \times 3'\ 2'' \times 3'\ 2''$ high, has a metal roof, the table top being protected by a transite covering. Inserted into the table top are 2 small sinks, each

FIG. 1.



$7'' \times 7''$, for draining water from condensers, water bath, etc. The sides of the hood are formed by windows of safety glass, the metal head, $5' \times 2'\ 6''$, is fitted on top with a very strong motor for the exhaustion of fumes, so that a front window becomes unnecessary. The hood is illuminated on the inside with 3 so-called "music room bulbs" of 18" length, which provide a very uniform and shadowless illumination. One,

two, or all three bulbs together can be used at one time. On the back wall are mounted: (*a*) a water pipe with three outlets, (*b*) the electric line with receptacles, (*c*) the compressed air line with one outlet, which is connected to a special blowing device similar to the one used in the Bell Telephone Laboratories. Five pieces of glass tubing are held by ball bearings in any position; a side arm of each tube is connected with rubber tubing to the feeding line. An air filter (12″ of absorbent cotton) is interposed to take out

FIG. 2.

The hood in Room A.

grease and dust from the air line. This outfit speeds up all the evaporations in small vessels or centrifuge cones by blowing air on the surface, thus being an important factor in saving time.

Inserted into the table top are the 4 outlets of the gas line, which is carried underneath the table top to the front; 4 needle valves regulate the gas and are placed in a panel in front of the table, thus eliminating reaching to the back of the hood if certain delicate procedures are performed under the hood. A similar arrangement is provided for the vacuum

line, which leads from the sink, where a glass water pump provides the necessary suction.

Into the transite top 2 sockets with standard taper for "Kewaunee Burette Rods" are inserted, which allow a simple exchange of any apparatus supported on one of these rods. This arrangement has been used successfully also on the other work benches. Below the table are three big drawers and a cabinet for storing apparatus and reagents.

The following apparatus is permanently set up under the hood:

(*a*) Electric crucible furnace, Cenco, size B, $4\frac{1}{2}'' \times 4\frac{1}{2}''$, for heating any precipitate or material over 600°C., as e.g., $BaSO_4$ in porcelain crucibles.

(*b*) Micro Carius furnace of American Instrument Company with rheostat, for 115 V, used for the digestion of halogen and sulphur compounds in sealed tubes and for all work where higher pressure is produced during the reaction in a sealed vessel.

(*c*) A water bath with constant level arrangement is supplied with glass holders for heating centrifuge cones and micro beakers.

(*d*) Two electric hot plates, General Electric Hotpoints, one of them round, the other with a square shaped copper plate, serve for any of the necessary heating procedures.

2. Beside the hood stands a *wooden sink*, with $24'' \times 18''$ inside dimensions, which is easily accessible. The depth of this sink is 20" in order to enable the rinsing of long combustion tubes and glass tubings. These wooden sinks are painted with an acid proof paint, S.D.O. du Pont Company, and have the advantages of being obtainable in any size, thus fitting with the other equipment, being comparatively inexpensive, and reducing the breakage of glassware in the cleaning procedures. A drain board, a dripping stand, and the shelf for the distilled water bottle are arranged on the side and over the sink. Behind the sink there are mounted the water pipes with 4 outlets, 2 of which are used for glass water pumps for suction lines and one for hot water. The suction lines go (*a*) under the hood, and (*b*) over a three way connection to the glass fume deduct of the Kjeldahl apparatus or to the suction line used on the table for qualitative technique in Room B.

3. The *small work table for the Kjeldahl* determination is placed beside the door. Its dimensions are 14″ × 2′ 3″ × 3′ 2″, and it is equipped with a transite top, into which one standard taper socket is inserted to hold the Kjeldahl apparatus by Kirk. An electric digestion stand, built in the Institute according to Drs. Allen and Sanigar, and glass fume deduct of newest design are mounted beside the distilling apparatus. The drawer in the table serves for storing the accessories for the Kjeldahl method, such as digestion flasks, etc., the cabinet for reagents of c.p. quality. A pipette holder of Fisher Scientific Co., is mounted on the wall over the table.

4. On the other side of the door one finds the *glass blowing table* with transite top, 18″ × 18″ × 3′ 7″, a small drawer for glass knives, sharpening block by Alber-Benedicks, working tools, etc., and three shelves. The outlets for compressed air, for gas and for electricity are inserted into a transite covering, which protects the wall from the heat of the Fisher blower.

5. Opposite the hood there is a *large work bench*, 6′ × 2′ × 3′ 2″ high, with gray linoleum top. A cabinet with 3 glass doors is placed at a distance of 18″ over the table. The dimensions of the cabinet are 6′ × 12″ wide × 3′ 4″ high, and inside are placed 3 shelves for the storage of chemicals and glassware. Beneath the bench are three drawers of different heights and a cabinet with a double wooden door. The work bench receives enough light during the daytime from the window, so that special illumination beside the central ceiling lamp becomes unnecessary.

6. Between the two windows of western exposure, which during the summertime are protected from the influence of the direct sun by awnings, is situated a *small table* with transite top, 23″ × 18″ × 2′ 10″, which rests partly on the window shelves and the radiator. It serves for the support of the electric drying oven, Thelco Gravity Convection, Size B.

Room B. Office Room and Room for Microscopical Investigations.—Due to the extremely dust loaded city air very fine work can not be accomplished without a device to remove these interfering substances, at least in one room. An air conditioned laboratory will remain one of the wishes of the

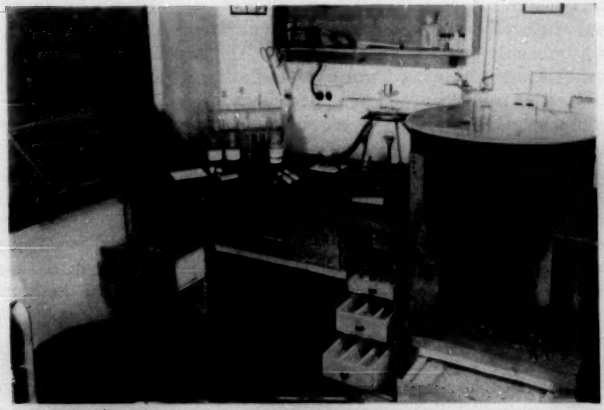
microanalysts until all gas burners can be eliminated from work benches and replaced by electric heaters. Nevertheless, the balance room and the microscope room should be equipped with the best in regard to dust filters. An office room is naturally not the ideal place for such an arrangement, since with the clothes and the shoes of the workers and visitors, enough dust is brought into the place to make the best filter device useless. But it was the only place available for this purpose and the described arrangement may be considered as a compromise between the ideal and the possible.

1. In order to have the room dust free, at least at the time of very delicate experiments, the floor is covered with linoleum and the walls are painted with Duco Enamel, both of which can be easily washed and cleaned. An *Airpilot* of the Standard Air Conditioning Company is built into one of the windows, the upper part of the latter made air tight with strips of cloth. The air filtering device has a capacity of 250 cubic feet per minute and a motor of 1/60 h.p. The filter itself can be easily replaced, such replacement being needed about every second month according to experience during the summer period of 1937. Over the door, which leads into Room C, another filter of the same type (1 *a*) is inserted into the wall, not only to allow clean air to enter into the other parts of the laboratory, but to prevent dust loaded air from the outer rooms entering the office room. A special weather stripping (elastic metal bands) on the door acts as an air tight seal. Since no special problem during the first period needed *complete* dust removal, the efficiency of the dust filter can be judged by the general appearance of the room only, which was satisfactory.

2. *Table for qualitative technique* (Fig. 3).—A special table for all the work in qualitative inorganic and organic microchemical analyses and preparative procedures has been designed, which is rather unique in this form. The leading idea was to have everything at hand, to avoid unnecessary movements and distractions. These are fundamental points, since otherwise the delicacy of these procedures may be reduced to such a point where their applicability becomes superfluous. The table, $5' \times 23'' \times 2'\,8''$ high, is covered with gray linoleum. On its right side a hand centrifuge, with a special

head for smaller micro centrifuge cones and capillaries, is fixed to the table. The projecting centrifuge handle is set in a small quadrant-well, cut out of the end of the table, thus, e.g., eliminating accidental knocking. The centrifuge is surrounded with a protecting shield and cover, in the back of which sufficient space for an electric centrifuge is left. A small shelf is placed over the table for a bottle with distilled water; another shelf carries different larger reagent bottles and has on its lower part one of the above mentioned "music room

FIG. 3.



The table for qualitative microtechnique in Room B.

bulbs" at a distance of 16" from the table top. This allows a very uniform illumination without shadows from the fingers and body of the analyst. Beside the table, partly on the window shelf, is a special reagent block with 5 tiers of holes for 120 reagent vials with Bakelite screw caps and protected by a glass window; this block is used for a number of special reagents in the drop test reactions and qualitative organic analysis. The drawers of the table are arranged in the following way: on the left side of the knee hole are three drawers for incoming samples and request sheets (nearly all

samples submitted for quantitative analysis are subjected to a preliminary qualitative organic elementary analysis, in order to select the correct procedure, sample weight, etc. according to the amounts of constituents and impurities), for all the small apparatus in Feigl's spot test technique, and for special equipment and working tools. A cabinet of 15″ height contains all stands, universal clamps, and metal apparatus. Over the knee hole is a 16″ wide drawer for slides, cover glasses, forceps, cells, small thermometers, etc., in general, for all finer working tools which should be at hand during the manipulations. On the right side are 7 compartments; the largest on top contains the reagent solutions for qualitative organic elementary analysis in vials with Bakelite caps and glass rods, small funnels, filterpaper, three drawers with three divisions each for capillaries, glass rods, pipettes, hard glass reaction tubes, copper wires for Beilstein tests, etc., three drawers for platinum loops, wires and spatula, stoppers and paper, and special apparatus such as specific gravity pipettes, viscosity apparatus, sublimation outfits, etc. Below the centrifuge, in the slightly protruding part of the table is a drawer for all centrifuge cones (different sizes and shapes), one for special apparatus such as distillation flasks, separatory funnels, extraction apparatus, and a cabinet. When not in use, the table may serve as the writing desk for one of the analysts.

3. The *microscope bench* (Fig. 4) was built by E. H. Sheldon and Co., Muskegon, Mich., according to a drawing and sample table by the Bell Telephone Laboratories. This bench fitted exactly in the corner of Room B and, for this reason, has not been especially designed. The top is of carbonized acid resisting material, in the middle of which a well is cut for the insertion of the microscope. This brings the microscope stage to the level of the bench top which permits of greater ease of manipulation as well as reducing arm fatigue. A hole in the rear of the well allows the insertion of an illuminating lamp and an optical arrangement, thereby eliminating disturbance by stray light. The back of the bench is constructed in such a way that a panel for all the electrical equipment and connections may be inserted. The resistances for a Reichert illumination stand (reflected light) and for the hot stage of Kofler

FIG. 4.

The microscope bench with Kofler's hot stage for melting point determination in Room B.

are mounted so that they can be removed easily. Two sockets with standard taper for metal rods are inserted into the table top, serving for the melting point apparatus (capillary technique) and micro molecular weight determination according to Pregl-Rast. Sufficient light is provided for these two pieces of apparatus by a desk lamp with flexible arm mounted on the right side of the table. Seven drawers are situated on the right side of the table, so that they can be opened without disturbing the microscopist. The two top drawers contain wooden blocks with 96 holes in each for the reagents according to the schemes of Chamot and Mason, and Benedetti-Pichler and Spikes; the others hold further microscope attachments, such as mechanical stage, microchemical manipulator of Alber, etc. The spare objectives and eye pieces are kept in a special small drawer on the left side of the bench. On the wall to the right of the bench is a shelf for 6 micro wash bottles which are kept in place by metal holders. Directly in back and above the microscope bench is a bank of shelves holding about 100 bottles which contain the necessary reagents and test solutions for semi-quantitative estimations as used in the scheme of Benedetti-Pichler and Spikes. A slide container and a specially designed drying box for preparations on slides used in the melting point determinations under the microscope are also placed on one of these shelves.

The microscope bench and table for qualitative technique form an actual unit, e.g., the end products from the preliminary procedures carried out on the qualitative table are identified under the microscope, or if a mechanical separation is first performed under the microscope with the microchemical manipulator on the microscope bench the separated products are then subjected to the analytical procedures on the qualitative table.

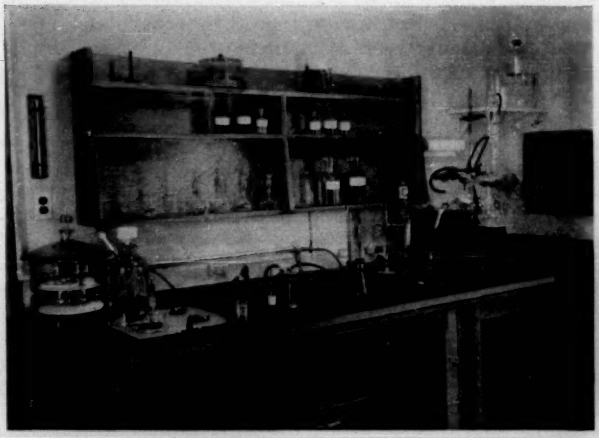
4. The *office equipment* consists of a writing desk, a movable typewriter stand, a filing cabinet for reference cards, microchemical reprints, etc., a bookshelf for the microchemical handbooks, and chairs.

5. General illumination of the room comes from the two windows, the ceiling lamp in the center, and a desk lamp on the writing desk.

Room C. Room for Suction and Filtration Procedures.—The original large room has been separated into two rooms by

a plywood wall in order to obtain a special balance room for the microchemical balances. The larger part, Room C, serves mainly for all operations which are connected with filtration and drying at certain temperatures, as well as for titration procedures. In this way most of the quantitative determinations are finished in Room C, which is the nearest to the balance room. Thus too much moving and carrying of finer weighing vessels, such as weighing bottles, charging tubes,

FIG. 5.



The work bench for suction, filtration, and vacuum drying procedures in Room C.

filter sticks, filter tubes, etc., are avoided, and the danger of losing the substance or spoiling the analysis before the last step is considerably reduced.

1. The *big work bench* or *suction table* (Fig. 5), 7′ 6″ × 3′ × 3′ 2″ high, has a gray linoleum top, into which a small sink, 7″ × 7″, 4 sockets with standard taper, and a special suction plate are inserted. This suction plate consists of a ground glass plate, 15″ × 15″ × ½″ thick, which is brought to the level of the table top. Four holes in this plate are used for the

air tight connection of 4 hard rubber rings to the pipe line, which leads in turn to the Hy-Vac pump, Cenco. Four needle valves allow the independent use of each of these suction areas, by which bell jars, Donau's suction apparatus or any other special arrangement may be evacuated. This suction device is used frequently for the drying of the filter tubes in vacuum as in phosphorus determinations, for the filtration of a few crystals in Donau dishes or Alber-Rodden platinum filter boats with porous bottom, or for filtration with porcelain Büchner funnels on a micro or macro scale. The available vacuum is naturally not very satisfactory, about 15 mm. Hg, because there are too many places where leakages may occur (valves, pipe lines, connections, etc.). In the same vacuum line lie 2 outlets for connecting rubber tubing with three way pieces, which in turn lead to the suction chamber of Emich's filter stick method, to the suction flask used in Pregl's filtering device, and to Benedetti-Pichler's or Pregl's drying block. The valves regulating the vacuum for these outlets are placed in the front of the table, where they are grouped in a removable panel to facilitate adjustments or repairs. The high-vacuum pump is placed in one of the cabinets of the suction table on a wooden case, which rests on 6 rubber stoppers in order to reduce the vibrations through the floor. The latter were very annoying, especially during the weighings on the microchemical balance. Another cabinet for reagents, and 8 small drawers for microchemical apparatus, weighing tools, and reserve apparatus are further fixtures of the table. A big shelf, 18″ × 22″ × 15″, with a partition, carries in special metal holders the different micro wash bottles for all filtration procedures, the flasks with interchangeable ground joints containing liquids of constant boiling point for the Abderhalden dryer, and different reagent bottles. The table is illuminated sufficiently from the central ceiling light, which has a 150 watt daylight bulb.

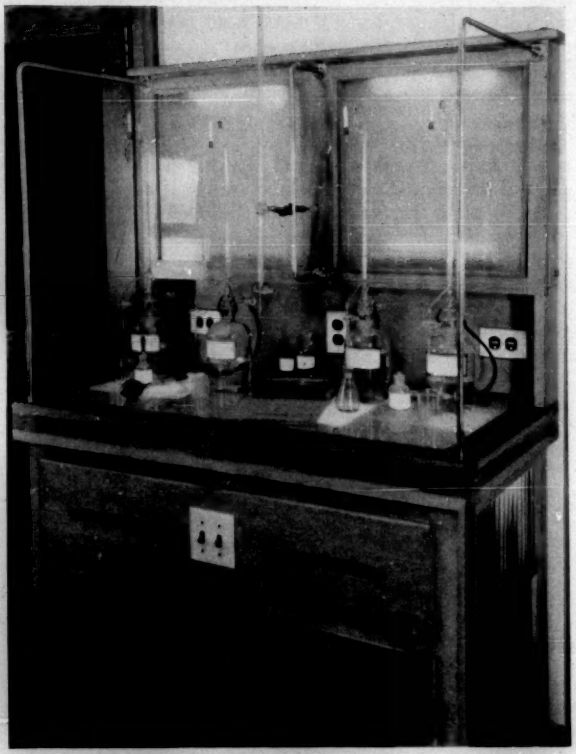
A few permanent pieces of equipment are placed on this table, one of which is the Abderhalden dryer (Scientific Glass Co.). It is provided with a special metal rack designed by Alber for opening and closing charging tubes without bringing the sample in contact with moist air, and interchangeable ground glass joints for flasks containing liquids of various

boiling points. Another drying apparatus is supported by one of the Kewaunee Burette rods with standard taper; it has been constructed by Unterzaucher for high vacuum drying. The substance in micro platinum boats is dried in square shaped weighing piggies at constant temperatures which are obtained by a gas-heated air bath. These two pieces of drying apparatus can be connected, if necessary, directly to the vacuum pump in order to give a better vacuum, or to the glass water pump over the sink. Drying under such carefully controlled conditions and in such apparatus is very important, since many of the biochemical products are extremely hygroscopic; only by preventing any access of air can accurate results and good checks in the different determinations be obtained.

2. Beside the suction table is the *wooden sink*, seen in Fig. 5, with 18″ × 22″ × 15″ inside dimensions; in the back of the sink are the water outlets for cold and warm water, one of which is used for a glass water pump.

3. A special feature in this room is the *titration table* (Fig. 6), 3′8″ × 24″ × 3′2″, which was designed to give the best results under varying conditions. It was desired to have equipment offering the possibility of changing the illumination according to the type of titration, and if possible to provide for the future use of UV-light necessary for fluorescent indicators. Inserted into the table top are two glass plates, ¼″ thick, ground on the lower side, the edges lined with gray linoleum, and easily removable. These glass plates are illuminated from underneath by 4 bulbs with reflectors, thus giving a very uniform illumination. In order to reduce the brightness of the underground light, two of the bulbs are connected to one sliding resistance, which allows dimming down the light gradually. If another color is preferable as background, colored glass filters, 6″ × 6″, of Pyrex glass are interposed in special slits by means of wooden holders. The color effects help considerably in observing weak endpoints by producing sharper color contrasts. The heat from the 4 bulbs must be carried off by means of efficient cross ventilation, which is made possible through slits in the sides of the table. Underneath the illumination control is a cabinet for the storage of the standard solutions. In the back wall of the table are inserted outlets for electric current used for hot plates if the

FIG. 6.



The titration table in Room C.

titration has to be carried out above room temperature. The reading of the graduations on the micro burettes is made easier through 2 uniformly illuminated glass plates, which are mounted in the back of the burettes; the light comes from 4 $11\frac{1}{2}$" "music room bulbs." The micro burettes are of the

standard type with automatic zero adjustment and refilling from the 1-liter stand bottles. Other burettes can be supported by clamps using 3 metal holders, which also may be used in certain cases for the support of covers, e.g., if work in UV-light should be carried out. The central metal holder can be exchanged for a bigger one by means of a simple spring clamp.

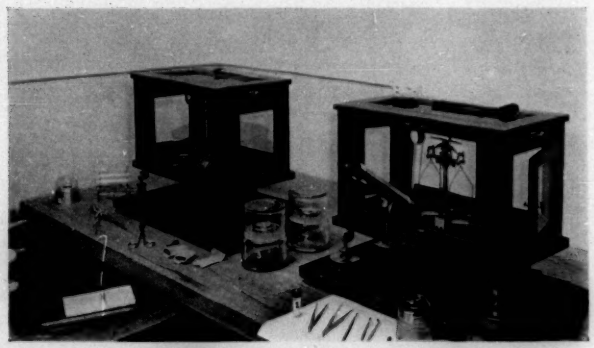
4. A *wooden stand*, 12″ × 16″ × 3′ 6″ high, for glass tubing, with 8 compartments which permit keeping apart glass of different dimensions and compositions, and a writing desk complete the furnishings of this room.

Room D. Balance Room.—As indicated previously, this room should be air conditioned, with a constant humidity of about 50 per cent., constant temperature of about 22° to 24° C., completely dust free, and vibrationless, in order to give the ideal surroundings for a room where such fine weighings are performed. Since it was impossible to insert these features into this laboratory at the present time, it was decided to select a room centered in the laboratory, and protected from the main influences of sudden temperature fluctuations by separating it from the other rooms by a gliding door. The vibrations, which, e.g., come from the motor for compressed air on the floor just above the balance room, have to be eliminated by the special construction of the balance table. Since the dust question could not be solved due to the central position of the Room D, and the necessity of avoiding any air currents, the room must be easy to clean, a postulate which is solved by covering the floor with gray linoleum and painting the walls with Duco Enamel paint.

1. The *balance table* (Fig. 7), 5′ × 29″ × 29″ high, has a 2″ thick oak top, which is supported by 2 iron triangular brackets. These brackets are inserted into the wall and insulated from vibrations of the walls by 1″ thick cork plates. Between the table plate and the iron brackets ½″ thick lead sheets are interposed to break up remaining short shocks and vibrations coming from the walls. The table top itself has no contact with the walls. In order to take care of the long vibrations and short shocks, which are not absorbed by the described breaking devices, the microchemical balances have

special supports: rubber pads, 1″ thick, are placed directly on the table and marble plates, 18″ × 14″ × 1″, rest upon them. Onto the marble plates are glued, in the position of the feet of the balance, 3 metal rings filled with rubber, on top of which are placed round aluminum sheets having no direct contact with the metal rings, the whole serving as shock-free balance support. With these arrangements no disturbances on the fine instruments could be noticed. Two microchemical balances of W. H. F. Kuhlmann, Hamburg, are in use, the one with an optical reader, the other with a telescope reading

FIG. 7.



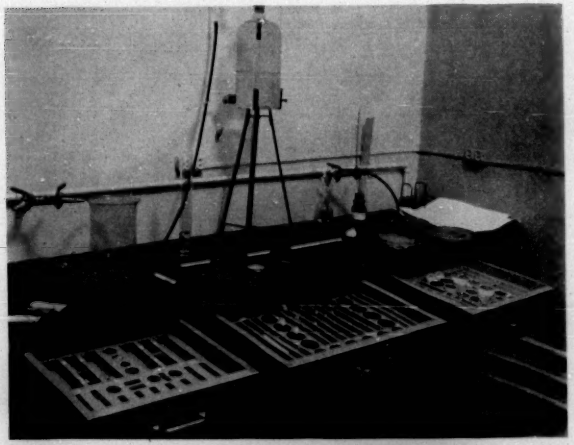
The microchemical balances in Room D.

device. Both work very satisfactorily. To prevent vibrations which may result from writing directly on the balance table, the operators use classroom type chairs with side arms serving as table upon which rests the note book.

2. A *hygrometer* and *barometer* indicate humidity and pressure, as well as temperature changes in the room. Temperature changes in the balance cases are observed on short stem Anschuetz thermometers. Daily records are kept of the atmospheric conditions in the balance room as well as of the sensitivity of the balances themselves.

3. A *work bench* (Fig. 8), 5′6″ × 1′6″ × 3′2″ high, has a linoleum top and serves for the aspirator train, used in the carbon and hydrogen determination by Niederl and Roth to replace the oxygen in the absorption tubes by air. Since the absorption tubes attain during this procedure the temperature of the balance room, no special difficulties in regard to weighing these tubes, a much discussed disadvantage, are observed. The apparatus of Hayman for viewing the absorption tubes

FIG. 8.



The work bench with absorption train and drawers for storing weighing vessels and corresponding tares in Room D.

is placed over the table on the wall, and any dust on the tubes, as well as static charges can be easily detected. A special feature of this work bench is the arrangement of the 3 drawers as containers for all weighing vessels and their counterpoises. It is a general rule in microanalysis to tare any of the vessels to be weighed on the microchemical balance with an object which has similar shape, same density and a weight of about 1 to 2 mg. less than the vessel. The accumulation of the numerous tares in the balance case and around the balances

could easily result in mistakes. For this reason the drawers have wooden blocks with openings for each vessel and its special counterpoise according to the shape and size, as seen in Fig. 8, thus having the vessels as well as the counterpoises ready for use when needed, protecting them from dust, avoiding mistakes in regard to counterpoises, and keeping track of the available apparatus. The microchemical group finds this arrangement very satisfactory to meet the numerous analyses of different types and considers it as an improvement of especial value for laboratories of similar type. One big cabinet with three doors forms the lower part of the work bench, where all "unit-apparatus" are stored, when not in use, such as the electrolysis apparatus of Clarke-Hermance, Abbe refractometer, reserve micro burettes, etc.

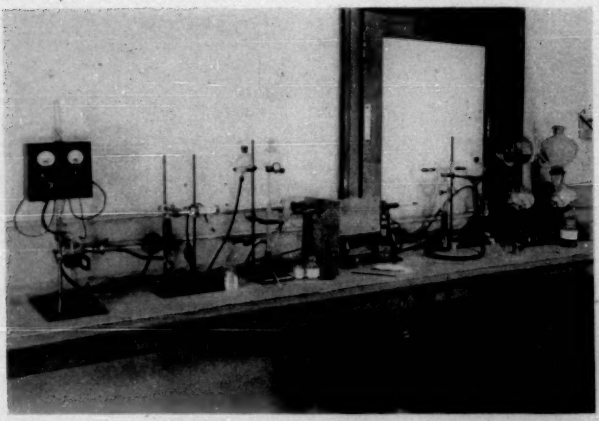
Room E. Room for Quantitative Organic Elementary Analysis.—It was intended to combine most of the heat producing procedures, i.e., all combustion methods, in one room. The largest room had to be selected for this special purpose, Room E, which opens to the corridor. It would have been more convenient, if this room had been provided with windows for a sufficient supply of fresh air. During the summer months the temperature in this room climbs up very fast and makes the working conditions unfavorable. For this reason as many of the gas burners as possible, especially the long burners, have been replaced by electric heating units, which do not give off so much of their heat to the surrounding air. The photographs for the Figs. 9 and 10 were taken before the replacement of the gas burners by electric heating elements.

1. Beside the door is one *long work bench* (Fig. 9), $12' \times 1' \times 3'\ 2''$, with transite top for the nitrogen-Dumas determination according to the procedure of Trautz and Niederl. As previously mentioned the long burner of the original method has been replaced by an electric furnace (Fisher Scientific Co.). Only two small drawers for working tools are inserted into this bench, leaving enough freedom for the legs of the analyst, who has to sit at the apparatus for a considerable period of the day. Beside the Dumas apparatus is space for the equipment necessary for the micro electrodeposition apparatus of Clarke and Hermance (Unit apparatus of Van

Name Co.), the micro muffle of Pregl, and a series of micro extraction apparatus.

2. Another *work bench* (Fig. 10), 4′ × 24″ × 3′2″ high, has a few sockets with standard taper inserted into the linoleum top. A small shelf with 5 metal holders serves for wash bottles used in the halogen or sulfur determinations according to the combustion procedure of Pregl, which is a permanent set up on this bench. In the table are 6 drawers of different

FIG. 9.



The work bench with apparatus for nitrogen determination, micro muffle, and unit apparatus for micro electrolytic deposition in Room E.

size, containing apparatus and accessories for the above mentioned determinations. Since the oxygen tank for the carbon and hydrogen determinations is placed near to the work bench, determinations needing oxygen are also carried out in this place, e.g., the phosphorus determination by the fusion method of Lieb.

3. Beside a *wooden sink*, with 18″ × 18″ × 20″ inside dimensions, is a storage space for the oxygen tank used in the carbon and hydrogen determination, and a nitrogen tank,

which is occasionally used elsewhere in the room for the methoxyl determination.

4. One *working table*, seen in Fig. 10 on the right, 6′ 6″ × 24″ × 3′ 2″ high, has a transite top, and serves for the permanent set up of the most important determination in the quantitative organic elementary analysis, the carbon and hydrogen determination. Beneath the table two big cabinets provide ample space for the storage of metal apparatus such

FIG. 10.

The work benches with apparatus for halogen determination by Pregl, and carbon and hydrogen determination by Niederl and Roth in Room E.

as the combustion stands, long burners, etc. The carbon and hydrogen apparatus is set up according to the experiences of Alber with the Niederl and Roth procedure. At the beginning gas heating only was used, which gave completely satisfactory analytical results. But due to uncomfortable heat production the long burner is replaced by a long electric heater of Von Czoernig, Philadelphia. The preheater is also supplied with an electric heating unit.

All the equipment mentioned under 1 and 4 obtain their

light from two 150 watt ceiling lights, the only special illumination being found in the next item.

5. The *preparation work bench*, 7′ 6″ × 2′ 5″ × 3′ 2″ high, has a linoleum top and serves for set ups which are not used permanently. Many of the finer manipulations are carried out here, such as filling of combustion tubes, preparation for the combustion, etc., therefore proper illumination is necessary. Again 2 "music room bulbs" gave the best solution of this problem, the big advantage being that the worker does not stand between the light source and the bench. The bulbs are mounted underneath the big 12″ wide shelf, which is erected at a distance of 18″ from the table top, leaving enough space for building up medium-sized apparatus. The 12 compartments of the shelf give ample space for the storage of all specially prepared reagents used in the organic quantitative analysis. Twelve drawers of different capacity in the work bench allow the storage of porcelain, glass, standard taper ware, stoppers, rubber tubing, etc.

6. A *clothes cabinet* occupies a space opposite the door.

This concludes the description of the microchemical laboratory. It may be stated here that the usual difficulties in starting microchemical procedures were reduced to a minimum, so that the microchemical group was able to run determinations 1 month after moving into the rooms. The main occupation at the beginning was to bring the mentioned methods into working condition and standardize all reagents. Besides, numerous problems have been attacked. A representative problem, which could be solved only by means of microanalytical procedures, is given to show how complex are the incoming problems and how close a cooperation between the various departments of the Research Foundation is necessary.

A certain biochemical investigation required the digestion in vitro of tumor tissue by proteolytic bacteria, i.e., *Clostridium histolyticum*. It was found later, that the filtrate, after being stored in flasks in the refrigerator for several weeks, yielded a few crystals. These crystals had apparently formed during the period of storage and were not sufficient to permit

analyses by ordinary methods. It was felt that they might in some way be related to certain activity which the freshly filtered solution possessed but subsequently lost. In order to identify the substance formed, a complete qualitative analysis was necessary. Approximately 20 white crystals of 20 μ to 30 μ side length were separated from adherent black particles by means of a microchemical manipulator. The solubility tests were performed on microscope slides or in centrifuge cones and showed that the crystals were insoluble in water, alkalies, or common organic solvents, but soluble in strong acids (e.g., 2-N HCl) with evolution of a few gas bubbles. In the solution one observed small fibrous particles, which were enclosed into the prismatic crystals as noticed also under the microscope by observation in polarized light. The results of a complete organic qualitative elementary microanalysis were as follows: trace of carbon (probably as CO_2), hydrogen (mostly in form of H_2O), nitrogen, phosphorus, absence of halides and sulfur. In ashing the crystals a grayish residue remained, which slowly dissolved in acids depending upon the temperature used in the ashing of the sample. An inorganic qualitative microanalysis had to be carried out, since only so little organic material was found. No elements in Groups 1, 2, and 3 were detected, but magnesium and a trace of calcium were the constituents of a precipitate in Group 4. Besides $NH_4^{\bullet}$, the presence of phosphate and of a little silicic acid was established. From the above analytical work it was concluded that the crystals were magnesium ammonium phosphate hexahydrate. This result could best be explained in the following way: in one step of the work the supernatant fluid of the digest was filtered through a Seitz-filter and a few asbestos fibers entered the filtrate. These fibers acted as nuclei of crystallization. Sufficient $NH_4^{\bullet}$ and $PO_4^{'''}$ were present in the solution to produce finally, together with some magnesium from the asbestos itself (magnesium and calcium silicate), the very distinct magnesium ammonium phosphate hexahydrate crystals. The size of the crystals could be accounted for by long storage in the refrigerator, which allowed, especially in the case of this compound, the growing of very distinct crystals. Since there was not enough substance available, no quanti-

tative determinations could be carried out, but the qualitative analysis was conclusive.

Due to the carefully planned equipment, as reported here in detail, the facilities of the laboratory were immediately made available to all analytical requests, and only in a few exceptional problems did minor changes have to be made. This may be considered as satisfactory proof for the efficiency of the microchemical laboratory as an integral part of the Biochemical Research Foundation.

INVESTIGATION OF VIBRATION OF CITY HALL IN PHILADELPHIA AND OF THE SUBWAY STRUCTURE BENEATH.

BY

J. E. SHRADER, Ph.D.,

Drexel Institute of Technology, Philadelphia, Pennsylvania.

Several years ago when the Broad Street Subway in Philadelphia was constructed, it was necessary that it should pass beneath the loop of the Market Street Subway on Filbert Street to the north of City Hall and beneath the loop at South Penn Square on the south. Between these points the Broad Street Subway extended beneath the City Hall at a depth of about forty-five feet below the curb. Later, when it was decided to abandon these Market Street loops around City Hall in favor of a direct route east and west beneath City Hall, it was necessary that this subway should pass beneath the Broad Street Subway and the foundations of City Hall itself.

The building of this subway beneath City Hall was an engineering undertaking of major importance. This project required that the tunnelling should be done in such a manner that the stability of the structure of City Hall should not be impaired.

The undertaking was the more difficult due to the fact that City Hall is a massive masonry structure with no structural steel or frame, and but little, if any, binding material had been used in the construction of the foundation. To extend this tunnel, it then required that a new foundation should be built which should replace that part of the old foundation of City Hall which had to be removed. To do all this without weakening the walls or introducing any weakness in the structure required great engineering skill.

This undertaking was finally successfully completed, and now the subway extends directly east and west beneath City

Hall and subway traffic has been diverted from the loops around City Hall so that much time is saved.

During the summer of 1936, an investigation was undertaken to determine the character and amount of vibration in and beneath City Hall and at various points in this new part of the subway system. The instrument used in this investigation was the Tri-Dimensional Vibrograph * designed by the writer. This instrument is of the seismographic type, so designed that it records photographically on a 70 mm. film the three components of vibration mutually at right angles to each other and shows amplitude wave form and frequency of vibration. Figure I is a photograph of this instrument. The amplitude of vibration is magnified about 330 times so that a vibration of .001 inch is represented by about 0.3 inch on the record. The frequency of vibration is indicated by a timing record produced by a vibrator which intercepts a beam of light at intervals of 1/60 second and these intervals are recorded as a succession of dots alongside the record of vibration.

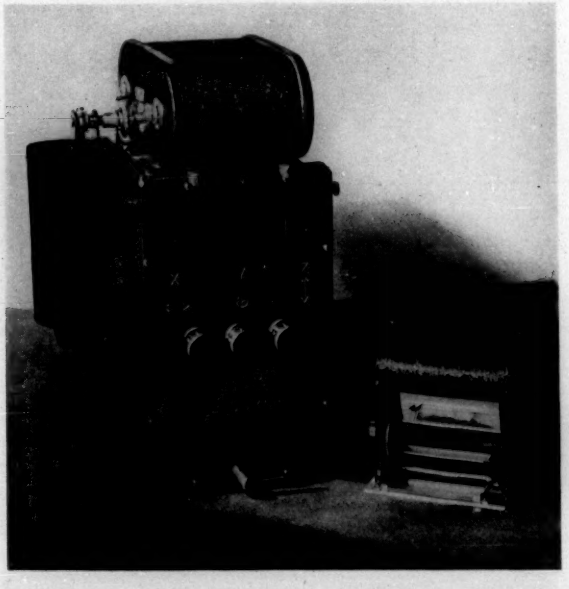
Certain points in City Hall and in the subway system were chosen where records were to be made, the aim being to choose such points where vibration of appreciable amounts were known to occur. At these points, records were made when the vibration was due to general traffic conditions and when due to the running of trains in close proximity. The records, together with data showing location and conditions under which these records were obtained are shown below. Figure II is a map of the subway system showing the loops of the Market Street Subway to the north and south of City Hall and the Broad Street Subway extending diagonally northwest from South Broad Street beneath City Hall. The Market Street Subway is also shown extending east and west directly beneath City Hall.

The point of most noticeable vibration in City Hall was in Common Pleas Courtroom, No. 3. Several observations were made here, some of which are shown in records 1 to 5. Other tests at points as indicated are shown in records 6 to 16.

* JOURNAL FRANKLIN INSTITUTE, 215, No. 4, April, 1933, p. 455.

While these records show that measurable vibration takes place in City Hall and in the subway structure, the amplitude of vibration does not exceed that which might be expected in a structure of this kind. The amplitude of vibration in City Hall itself scarcely exceeds 0.001 inch and this could by no means be taken to indicate that there exists any

FIG. I.

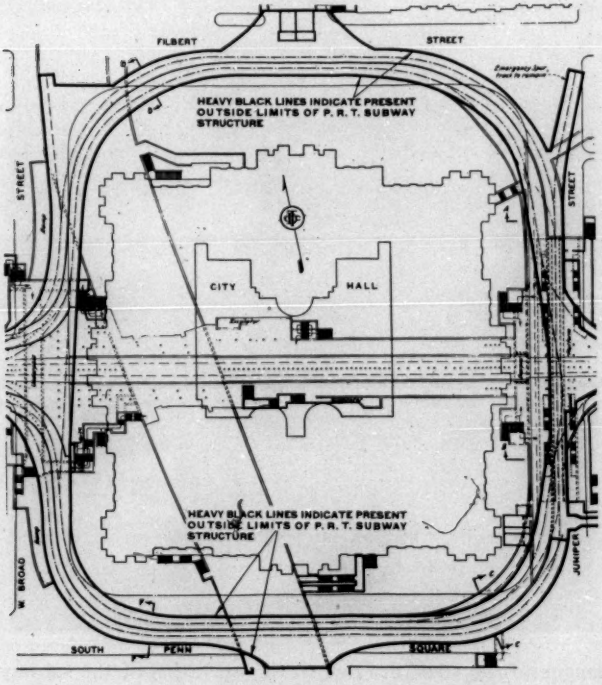


danger to the structure due to the operation of the subway beneath. Neither is the amplitude or frequency of vibration of such a value that physical discomfort should result except that which results from noise.

In fact, the vibration resulting from walking on the floor in the courtroom, as shown in record 5, largely exceeds any

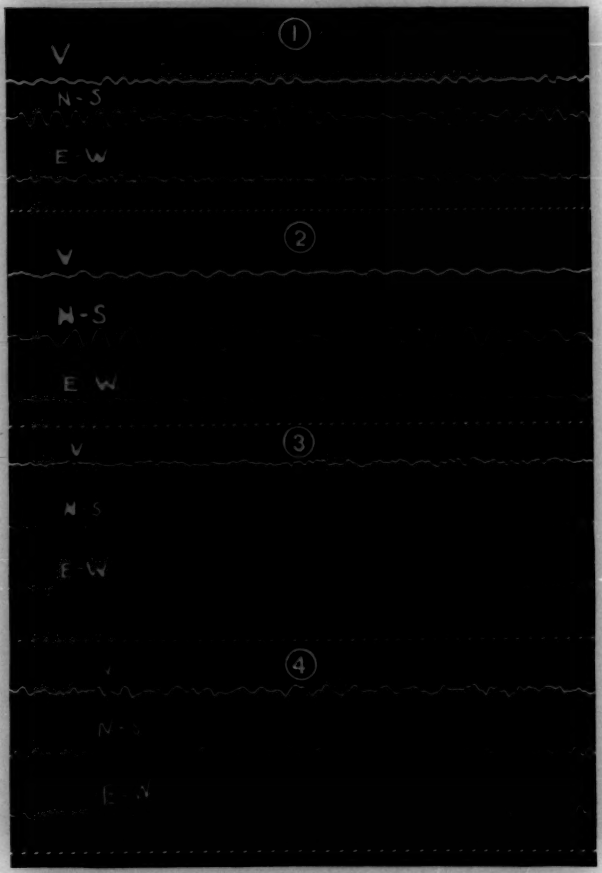
vibration due to the operation of the subways. While the magnitude of the vibration resulting from subway operation is small, this results in considerable noise which in these days of modern improvements is a source of considerable annoy-

FIG. II.



ance. The elimination of that vibration transmitted through the elastic structure which results in noise is a considerable problem in itself, and since this construction is completed, this cannot be remedied except at enormous expense. The

RECORD OF VIBRATION.

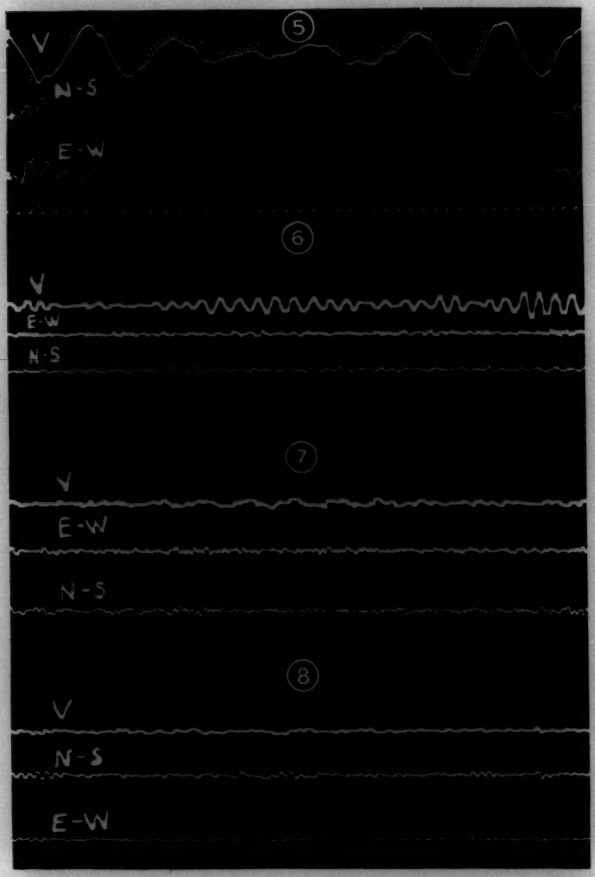


1. At the center of judge's bench, Common Pleas Court, No. 3, while subway trains were running beneath.

2. Same as No. 1 except that trains were not running immediately below. It is to be noted that these records differ but slightly.

3. On dais beside railing in Common Pleas Court Room, No. 3. No train was running but there was considerable noise from traffic. Vibrations are of small amplitude.

4. On floor in front of railing in Common Pleas Court Room No. 3. Trains running beneath.

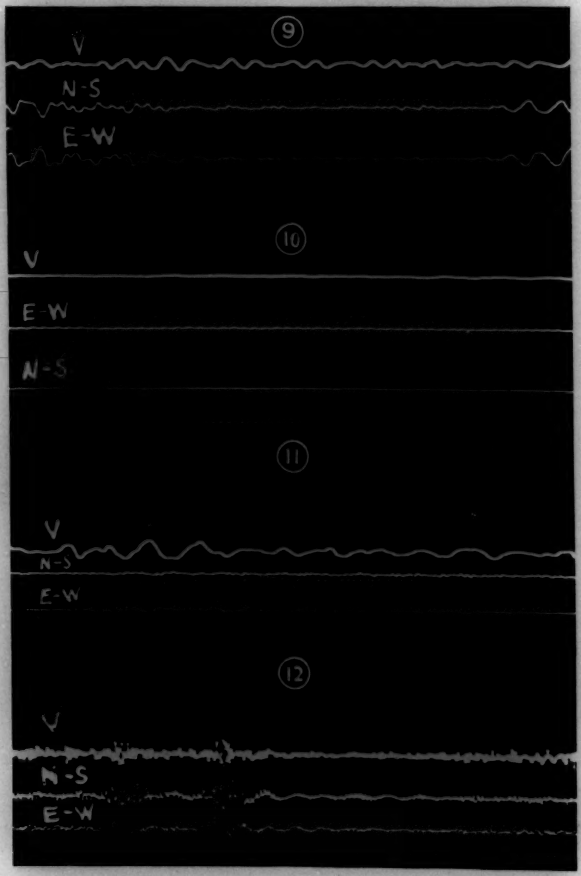


5. Same location as No. 4 with a person walking on the floor seven feet away. Each step is clearly shown by increased amplitude of vibration. The vertical vibration is largest, as might be expected.

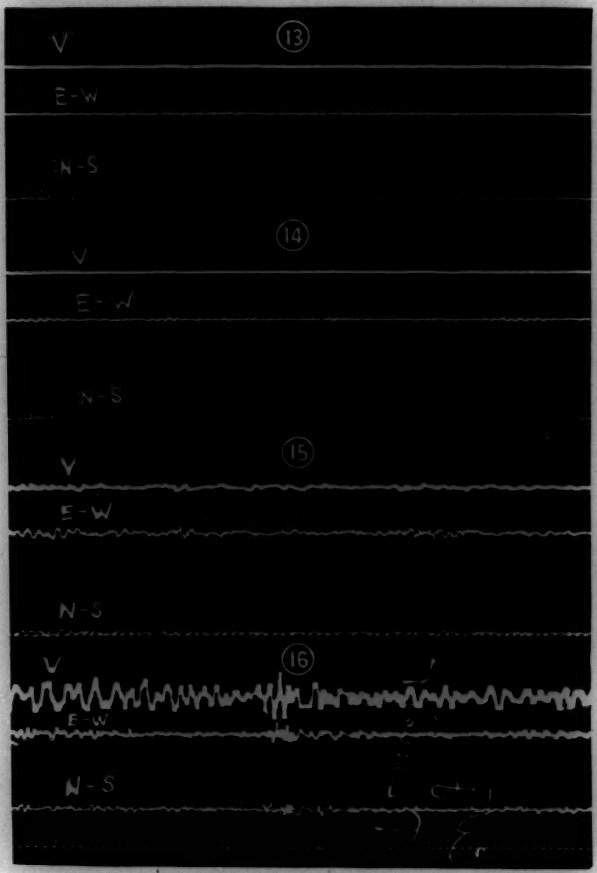
6. On second floor corridor over West Market Street entrance

7. On ground floor of northwest stair well.

8. On ground in the west entrance.



9. On ground in the east entrance.
10. On second floor over east entrance.
11. City Hall Station, North Central mezzanine over north-bound Broad Street, No. 4 track. Record made during passage of west-bound Market Street Subway train.
12. On north-bound Broad Street Station under west-bound Market Street Subway. Record made during passage of west-bound Market Street Subway train.



13. Same as No. 12. Record made during entrance of north-bound Subway train.
14. Under northwest corner of City Hall beside Subway surface cars over Broad Street. Record made during passage of west-bound subway surface car of weight 37,000 lbs.
15. Same as No. 14 except for larger car (45,000 pounds).
16. Same as 15 except that car was run at higher speed, which markedly increased the amplitude of vibration.

solution of this problem lies in isolating the source of vibration from the rigid structure, thus preventing the transmission of that vibration of small amplitude which results in noise.

The subject of noise elimination is one of increasing importance and in our modern structural projects it is given much consideration, so that in engineering projects of the future the problem of noise elimination will undoubtedly be given the attention it deserves.

Bombproof Power Plants for Europe's Chemical Industries.—C. H. S. TUPHOLME in the News Edition of *Industrial and Engineering Chemistry*, Vol. 15, No. 17, gives a typical example of the design of a bombproof power station which is an illustration of the preparations being made in Europe for war. Such undertakings have been made principally for the explosives producing and allied chemical industries. The plant contains a Velox steam generator and its output is for 20,000 kw. It is designed to be lodged in a tunnel excavated in rock and the small space requirements of the Velox make it very suitable. The steam generator to produce 16,000 lb. per hour of steam, the turbine with its condenser, the electric generator, all accessories, and the switch-gear plant are so housed. There are oil tanks in the bombproof chamber and the capacity of the tanks allows of generating 2,000,000 kw.-hr. which is sufficient for six to seven days service. The consideration of the possibility of existing plants being put out of operation by hostile action resulted in designs being prepared for standby plants.

R. H. O.

SOLUTION OF VARIABLE CIRCUITS BY MATRICES.

BY

LOUIS A. PIPES, Ph.D.,

Electrical Engineering Department,
The Rice Institute.

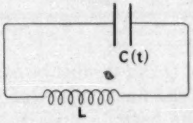
I. SUMMARY.

It is the purpose of this paper to present a method for the numerical solution of circuits whose parameters vary with the time. The method is not limited to electrical networks but any electrical or mechanical system whose behavior may be expressed by an ordinary homogeneous linear equation with variable coefficients. This method is particularly well adapted to the solution of the free oscillations of circuits whose parameters are periodic functions of the time. This class of problem is of great technical interest both in engineering and in physics.

II. THE FREE OSCILLATIONS OF A CIRCUIT HAVING A PERIODICALLY VARYING CAPACITY.

Before considering the general theory, let us consider the solution of the circuit shown in the diagram.

FIG. 1.



Let a condenser of variable capacitance $C(t)$ be connected in series with an inductance L. Let an initial charge Q_0 be placed on the condenser at $t = 0$, and let the subsequent behavior of the circuit be investigated. For simplicity, it is supposed that the resistance of the circuit is negligible. The method, however, is not limited to this restriction, as will be shown.

1. The Equation of the Circuit.

The equation satisfied by the charge Q on the condenser is:

$$L\frac{d^2Q}{dt^2} + \frac{Q}{C(t)} = 0$$

or

$$\frac{d^2Q}{dt^2} + \frac{Q}{LC(t)} = 0.$$

For simplicity let

$$\frac{1}{LC(t)} = \omega^2(t);$$

therefore

$$\frac{d^2Q}{dt^2} + \omega^2(t)Q = 0;$$

this is the equation of the circuit.

This equation must be solved subject to the initial boundary conditions:

$Q = Q_0$ $\quad Q_0$ = the initial energy charge,
at $t = 0$;
$\dot{Q} = \dot{Q}_0$ $\quad \dot{Q}_0$ = the initial current.

2. The Matrix Equation of the Circuit.

The method consists of splitting the time interval from $t = 0$ to $t = t$ into short time intervals $t_s - t_{s-1}$ over which the variable parameter may be considered constant.

$$t_s - t_{s-1} = T.$$

. 1 . 2 . 3 . 4 . 5 . —— .

Since the values of Q and $\dot{Q}$ must be continuous throughout successive intervals, the final values of Q and $\dot{Q}$ at the end of one interval are the initial values of the variables for the next interval.

That is, we approximate our actual equation with variable parameters by a set of equations whose parameters are fixed throughout each of the short intervals of length T. At first glance, this appears to be a formidable task. However by matrix multiplication, as we shall see, the task is simple and may be reduced to a routine.

Assume for the time being that the coefficient $\omega^2(t)$ of

$$\frac{d^2Q}{dt^2} + \omega^2(t)Q = 0$$

is fixed for a short interval T.

The well-known solution of this equation if ω^2 is constant is:

$$Q = C_1 \sin \omega t + C_2 \cos \omega t,$$
$$\dot{Q} = \omega C_1 \cos \omega t - \omega C_2 \sin \omega t,$$

where C_1 and C_2 are constants to be determined from the initial conditions.

Let $Q = x_1$ and $\dot{Q} = x_2$; therefore

$$x_1 = C_1 \sin \omega t + C_2 \cos \omega t,$$
$$x_2 = \omega C_1 \cos \omega t - \omega C_2 \sin \omega t$$

or in matrix form

$$\left\| \begin{matrix} x_1 \\ x_2 \end{matrix} \right\| = \left\| \begin{matrix} \sin \omega t & \cos \omega t \\ \omega \cos \omega t & -\omega \sin \omega t \end{matrix} \right\| \cdot \left\| \begin{matrix} C_1 \\ C_2 \end{matrix} \right\|$$

For brevity, let

$$\left\| \begin{matrix} x_1 \\ x_2 \end{matrix} \right\| = [x] \qquad \left\| \begin{matrix} C_1 \\ C_2 \end{matrix} \right\| = [C]$$

and let

$$[A(t)] = \left\| \begin{matrix} \sin \omega t & \cos \omega t \\ \omega \cos \omega t & -\omega \sin \omega t \end{matrix} \right\|;$$

let

$$[x^0] = \left\| \begin{matrix} x_1{}^0 \\ x_2{}^0 \end{matrix} \right\| = \left\| \begin{matrix} Q_0 \\ \dot{Q}_0 \end{matrix} \right\|$$

be the initial values of the charge and the current at $t = 0$.

Let $[A_1(T/2)]$ be the mean value of $[A(t)]$ in the first interval.

$$[A_1(T/2)] = \left\| \begin{matrix} \sin \omega_1 T/2 & \cos \omega_1 T/2 \\ \omega_1 \cos \omega_1 T/2 & -\omega_1 \sin \omega_1 T/2 \end{matrix} \right\|,$$

where ω_1 represents the mean value of the variable parameter in the first interval.

Then, to determine the constant matrix $[c]$ we use:

$$[x^0] = [A_1(0)][c].$$

Let us multiply both sides of this equation by the inverse matrix of $[A_1(0)]$ denoted by $[A_1(0)]^{-1}$.

The reader who is not acquainted with the elements of matrix algebra may consult "Introduction to Higher Algebra" by Bocher, McMillan, or the excellent treatise "Communication Networks" by Guillemin, J. Wiley, Vol. II. However, the example which will be given will make the manipulation clear.

Multiplying we obtain:

$$[A_1(0)]^{-1}[x^0] = [A_1(0)]^{-1}[A_1(0)][c]$$

or therefore

$$[c] = [A_1(0)]^{-1}[x^0].$$

Let $[x'(T)]$ denote the values of the variables at the end of the first interval. Then $[x'(T)]=[A_1(T)][A_1(0)]^{-1}[x^0]$.

This provides the initial conditions for the next interval.

Let $[A_2(T/2)]$ be the mean value of $[A(t)]$ in the interval 2. That is,

$$[A_2(T/2)] = \begin{Vmatrix} \sin \omega_2 T/2 & \cos \omega_2 T/2 \\ \omega_2 \cos \omega_2 T/2 & -\omega_2 \sin \omega_2 T/2 \end{Vmatrix},$$

where ω_2 is the average value taken by $\omega(t)$ in the interval 2.

Then, since $[x'(T)]$ is the initial value of the variables in the second interval $[x^2(T)] = [A_2(T)][A_2(0)]^{-1}[x'(T)]$.

Note: $[x^2(T)]$ does not mean $[x(T)]$ squared, but $\begin{Vmatrix} x_1^2(T) \\ x_2^2(T) \end{Vmatrix}$

is the value of $[x]$ at the end of the second interval. Similarly, in the nth interval, if $[A_n(T/2)]$ be the mean value of $[A(t)]$ in the nth interval, and $[x^{n-1}(T)]$ be the initial value in the nth interval, then

$$[x^n(T)] = [A_n(T)][A_n(0)]^{-1}[x^{n-1}(T)].$$

To find $[x]$ in any interval, therefore, we have to multiply a chain of matrices.

Analytically, the chain multiplication may be expressed

by the product

$$[x^n(T)] = \prod_{n=1}^{n} [A_n(T)][A_n(0)]^{-1}[x^0].$$

Before giving an example, let us consider the case where the variations of the capacity are periodic. That is where, $\omega^2(t + T_1) = \omega^2(t)$, T_1 is the period of variation.

3. Mathieu's Equation.

In the case of periodic variation our equation is

$$\frac{d^2Q}{dt^2} + \omega^2(t)Q = 0,$$

where

$$\omega^2(T_1 + t) = \omega^2(t).$$

This is the famous equation of Mathieu or Hill. The number of physical and technical problems that come under its scope is unlimited. The range extends from the vibrations of the side rods of a locomotive to those of a small clock motor. This equation has received considerable attention from astronomers because of its great importance in this field. The usual series solution is most tedious and frequently converges slowly.

It will now be shown that the solution of Mathieu's equation may be simply effected numerically by carrying out a matrix multiplication for one cycle of the variation of $\omega^2(t)$. Further values may be obtained from a certain recursion formula which will be established. For this purpose it is necessary to establish the following theorem.

Theorem.—The solution of the equation $(d^2Q/dt^2) + \omega^2(t)Q = 0$, where $\omega^2(t + T_1) = \omega^2(t)$ is of the form $Q(t + t_1) = \mu Q(t)$, where μ is the ratio of the value of the solution at the end of the first cycle of variation of $\omega^2(t)$ to the initial value of Q at the beginning of the cycle.

Proof.—Let the solution at $t = 0$ be Q_0, that is, $Q_0 = Q(0)$. Now, at the end of a cycle of the variation of $\omega^2(t)$, that is, at $t = T_1$ let the solution be μQ_0. That is, $Q(T_1) = \mu Q_0$.

We now enter the second cycle of the variation of $\omega^2(t)$ with the initial value of Q, μ times as great as it was before. Because of the property $\omega^2(T_1 + t) = \omega^2(t)$ the equation is

the same as it was throughout the first cycle. Since the only change in the situation is the fact that the initial conditions on Q are such that Q is μ times as great, it follows that throughout the second cycle Q will have μ times the value it had at corresponding points of the first cycle, or, analytically

A rigorous discussion of this theorem will be found in Whittaker and Watson's "Modern Analysis," p. 412.

$$Q(t + T_1) = \mu Q(t).$$

This is of great importance. We now know the nature of the solution.

To find the motion during the third cycle of the variation of $\omega^2(t)$ let

$$t = T_1 + t_1.$$

Therefore

$$Q(2T_1 + t) = \mu Q(T_1 + t_1),$$

but

$$Q(T_1 + t_1) = \mu Q(t_1)$$

and hence

$$Q(2T_1 + t_1) = \mu^2 Q(T_1 + t_1).$$

Similarly in the nth cycle,

$$Q(nT_1 + t) = \mu^n Q(t).$$

We see from this general discussion that if $|\mu| < 1$ the charge Q decreases. If $|\mu| = 1$, the charge is oscillatory. If $|\mu| > 1$, the charge continues to increase. In the first case the initial electrostatic energy is dissipated in doing work against the agent causing the variation in the system. In the second case we have essentially a condition similar to one which would prevail if there were no variation in the capacitance. In the last case the charge builds up. In this case energy is extracted from the system causing the variation of the capacitance and the energy of the electrical system increases. In the analogous mechanical problems the motion is said to be unstable.

The current $\dot{Q} = i$ behaves in the same manner.

$$i(nT_1 + t) = \dot{Q}(nT_1 + t) = \mu^n \dot{Q}(t) = \mu^n i(t).$$

It is seen from the discussion that it is only necessary to carry out our matrix step solution for the first cycle of

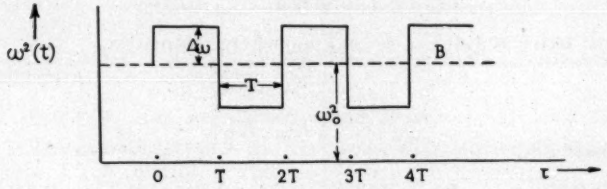
variation of $\omega^2(t)$ and this determines μ. Having determined μ, we compute the subsequent behavior from

$$Q(t + T_1) = \mu Q(t),$$
$$Q(t + T_1) = \mu Q(t).$$

As an example of the method, let it be required to determine the behavior of a circuit whose capacity is varied in a rectangular manner. This is chosen because it has been worked out by van der Pol and Strutt, *Phil. Mag.*, **5**, p. 18 (1928). In particular we shall inquire when the circuit is stable.

Let the variation in $\omega^2(t)$ be represented graphically by that is,

FIG. 2.



$$\omega^2(t) = \omega_0^2 + \Delta\omega \qquad 0 < t < T,$$
$$\omega^2(t) = \omega_0^2 - \Delta\omega \qquad T < t < 2T;$$

let

$$P_1 = \sqrt{\omega_0^2 + \Delta\omega},$$
$$P_2 = \sqrt{\omega_0^2 - \Delta\omega}.$$

During the first interval

$$[A_1(t)] = \begin{Vmatrix} \sin P_1 t & \cos P_1 t \\ P_1 \cos P_1 t & -P_1 \sin P_1 t \end{Vmatrix},$$

$$[A_1(0)] = \begin{Vmatrix} 0 & 1 \\ P_1 & 0 \end{Vmatrix},$$

$$[A_1(0)]^{-1} = \frac{1}{P_1} \begin{Vmatrix} 0 & 1 \\ P_1 & 0 \end{Vmatrix}.$$

Similarly, during the second interval

$$[A_2(t)] = \begin{Vmatrix} \sin P_2 t & \cos P_2 t \\ P_2 \cos P_2 t & -P_2 \sin P_2 t \end{Vmatrix},$$

$$[A_2(0)]^{-1} = \frac{1}{P_2} \begin{Vmatrix} 0 & 1 \\ P_2 & 0 \end{Vmatrix}.$$

Therefore at the end of the second interval

$$[x^2(T)] = [A_2(T)][A_2(0)]^{-1}[A_1(T)][A_1(0)]^{-1}[x^0].$$

By routine multiplication of the matrices

$$[A_2(T)][A_2(0)]^{-1}[A_1(T)][A_1(0)]^{-1}$$

we arrive at $[x^2(T)] = [K][x^0]$ where the matrix

$$[K] = \begin{Vmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{Vmatrix}$$

and

$$P_2P_1K_{11} = (-P_1^2 \sin P_1T \sin P_2T + P_2P_1 \cos P_1T \cos P_2T),$$
$$P_2P_1K_{12} = (P_1 \sin P_2T \cos P_1T + P_2 \cos P_2T \sin P_1T),$$
$$P_2P_1K_{21} = (-P_1^2P_2 \cos P_2T \sin P_1T - P_2^2P_1 \sin P_2T \cos P_1T),$$
$$P_2P_1K_{22} = (P_2P_1 \cos P_2T \cos P_1T - P_2^2 \sin P_1T \sin P_2T).$$

It must be realized that in the usual problem actual numerical values would be substituted for the elements of $[K]$.

However, in the case we are interested in determining the stability of the system.

Now $[x^2(T)] = \mu[x^0]$ therefore $\mu[x^0] = [K][x^0]$ or $[\mu I - K][x^0] = 0$. $[I]$ is the unit matrix.

Now $[\mu I - K]$ is the characteristic matrix of $[K]$.

The roots of $\mu I - K = 0$ are called the latent roots of $[K]$.

Now

$$[\mu I - K] = \begin{Vmatrix} \mu - K_{11} & -K_{12} \\ -K_{21} & \mu - K_{22} \end{Vmatrix}$$

and the latent roots are given by

$$\mu^2 - \mu(K_{11} + K_{22}) + (K_{11}K_{22} - K_{21}K_{12}) = 0.$$

Substituting the values of K_{11} etc. we obtain:

$$\mu^2 - 2\mu\left(\cos P_1T \cos P_2T - \frac{P_1^2+P_2^2}{2P_1P_2}\sin P_1T \sin P_2T\right) + 1 = 0.$$

Let

$$B = \left(\cos P_1T \cos P_2T - \frac{P_1^2 + P_2^2}{2P_1P_2}\sin P_1T \sin P_2T\right);$$

therefore $\mu = B \pm \sqrt{B^2 - 1}$, and if $|B| > 1$ one of the latent roots is greater than unity and the motion is unstable.

If $|B| \leq 1$ the motion is stable.

This is the result more laboriously obtained by van der Pol and Strutt.

IV. APPLICABILITY OF THE METHOD.

The example given is the trivial case that only requires two steps. The solution in this case is exact, if the variation of $\omega^2(t)$ is only known in the form of a graph, the cycle may be broken up into small intervals and the various $[A_n(T)]$ computed. From this $[A_n(T)]^{-1}$ is determined and the solution is then carried out by matrix multiplication. The solution at any interval n is given by

$$[x^n(T)] = \prod_{r=1}^{n} [A_r(T)][A_r(0)]^{-1}[x^0].$$

V. THE GENERAL CASE.

So far we have considered a homogeneous linear equation of the second order. This method is applicable in general. The coefficients must, however, be single valued functions of the independent variable and they must remain finite in the interval. This restriction is usually met in physical problems.

The general equation may be written

$$\frac{d^ny}{dt^n} + P_1(t)\frac{d^{n-1}y}{dt^{n-1}} + \cdots + P_n(t)y = 0,$$

where the $P_k(t)$ are single-valued analytic functions of t.

Then $$[A_1(T)] = \begin{Vmatrix} e^{\alpha_{11}T} & \cdots & e^{\alpha_{n1}T} \\ \alpha_{11}e^{\alpha_{11}T} & \cdots & e\alpha_n e^{\alpha_{n1}T} \\ \cdot & \cdots & \cdot \\ \alpha_{11}{}^{n-1}e^{\alpha_{11}T} & \cdots & \alpha_{n1}{}^{n-1}e^{\alpha_{n1}T} \end{Vmatrix},$$

where $\alpha_{11}, \alpha_{12}, \cdots \alpha_{n1}$ are the roots of $\alpha^n + P_{11}\alpha^{n-1} + \cdots P_{n1} = 0$ and $P_{11}, P_{21}, \cdots P_{n1}$ are the values of the coefficients in the first interval.

And in general

$$[A_r(T)] = \begin{Vmatrix} e^{\alpha_{1r}T} & \cdots & e^{\alpha_{nr}T} \\ \alpha_{1r}e^{\alpha_{1r}T} & \cdots & \alpha_{nr}e^{\alpha_{nr}T} \\ \cdot & \cdots & \cdot \\ \alpha_{1r}{}^{n-1}e^{\alpha_{1r}T} & \cdots & \alpha_{nr}{}^{n-1}e^{\alpha_{nr}T} \end{Vmatrix},$$

where $\alpha_{1r}, \alpha_{2r}, \cdots \alpha_{nr}$ are the roots of $\alpha^n + P_{1r}\alpha^{n-1} + \cdots + P_{nr} = 0$ and $P_{1r}, P_{2r} \cdots P_{nr}$ are the values of the coefficients in the rth interval.

If $$[x^0] = \begin{Vmatrix} x_1{}^0 \\ x_2{}^0 \\ \cdots \\ x_n{}^0 \end{Vmatrix} \quad \begin{matrix} x_1{}^0 = y_0 \\ x_2{}^0 = \dot{y} \\ \cdot \quad \cdot \quad \cdot \quad \cdot \\ x_n{}^0 = \dfrac{d^{n-1}}{dt^{n-1}} y \quad \text{at} \quad t = 0. \end{matrix}$$

Initial values of y and the $(n-1)$ derivatives

Then the solution of the nth interval:

$$[x^n(T)] = \prod_{r=1}^{n} [A_r(T)][A_r(0)]^{-1}[x^0].$$

The accuracy of the method depends on choosing the step intervals small where the variable coefficients fluctuate widely. A computer equipped with a comptometer is able to obtain the inverse matrices and perform the matrix multiplications with great ease.

VI. BIBLIOGRAPHY.

1. "Introduction to Higher Algebra," by M. Bocher. McMillan.
2. "Communication Networks," Vol. II. Guillemin. J. Wiley.
3. "Modern Analysis," Chapter 19. Whittaker and Watson, Cambridge.
4. "On the Oscillations of a Circuit Having a Periodically Varying Capacitance," by W. L. Barrow. *I. R. E.*, Feb. 1934, p. 201–212.

5. "A Further Study of Oscillatory Circuits Having Periodically Varying Parameters," by W. L. Barrow, D. B. Smith and F. W. Bauman. JOURNAL OF THE FRANKLIN INSTITUTE, 221, No. 3, March 1936.

6. "On the Stability of the Solutions of Mathieu's Equation," van der Pol and Strutt. *Phil. Mag.*, 5, p. 18 (1928). (This paper contains an extensive bibliography of the applications of Mathieu's Equation in engineering and physics.)

7. "Lectures on Matrices," by J. H. M. Wedderburn. American Mathematical Society Colloquium Publications, Vol. XVII. (This volume contains 549 references covering the international literature on matrix algebra.)

Long Pipe Line Bridge.—H. W. KEYSER. (*The Oil Weekly*, Vol. 86, No. 13.) Completion of the longest suspension pipe line span in the Rocky Mountains marks another advancement in modern oil transportation. The span was erected by Sinclair Wyoming Pipe Line Co. across Salt Creek in central Wyoming. Traveling 480 feet between the end towers of the bridge, the six inch line, at its highest point, is 45 feet above the bed of the creek over which it was carried so as to provide a straight gravity flow of crude to the gathering station. The line is suspended on cables connecting the three towers similar to a suspension bridge. Supporting cables are fastened to the bracing legs of the tower, and not snubbed in the ground where rust and corrosive action of the alkaline soils would cause rapid deterioration. Engineers were faced with the problem of bridging an unusually broad wash, and still keeping the line sufficiently straight to prevent any excess friction from slowing the flow of oil.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

CHARACTERISTICS OF THE IONOSPHERE AT WASHINGTON, D. C.

Radio waves at high frequencies over both short and long distances, and at low frequencies over the longer distances, are transmitted from sending to receiving stations by reflection from the ionosphere (upper ionized region of the earth's atmosphere). The ionosphere transmits radio waves at some frequencies much more efficiently than at other frequencies, but the condition of the ionosphere changes in a complex manner so that the best frequency for a given distance varies with the time of day, season of the year, and also with the 11-year sunspot cycle. In addition, there are sometimes disturbed conditions in the ionosphere which introduce further variations in the choice of frequencies.

The ionosphere generally includes two principal strata of ionized air; the E layer, at a virtual height of about 115 kilometers, and the F layer, at heights varying from 230 to 500 or more kilometers. During the daytime in the summer there are three principal strata, the F layer separating into two, the F_1 layer at about 230 kilometers, and the F_2 layer at heights varying from about 300 to 600 kilometers. For radio waves transmitted vertically upward and reflected down to the same locality, if the frequency is gradually increased, a frequency is finally reached at which the waves penetrate a given layer and are no longer reflected from it. The highest frequency which is reflected from a layer when transmitted vertically upward is called the critical frequency of that layer. When the transmitter and receiver are at a distance from one another so that the waves are reflected obliquely from the ionosphere, higher frequencies can be reflected, but there is a definite maximum useful frequency for any distance.

Because of the importance of the ionosphere in controlling radio transmission, a knowledge of its behavior and its variations from time to time is essential to the communication engi-

* Communicated by the Director.

neer and in many scientific investigations. The Bureau is now publishing monthly summaries of ionosphere conditions in the *Proceedings* of the Institute of Radio Engineers. Data on ionosphere conditions for January to July, 1937 were published in the September issue of that periodical, and the October issue contained the data for August. These bulletins will be continued each month.

In these summaries the monthly averages for each of the 24 hours of the day, of the critical frequencies and virtual heights are given graphically. Some of these data are obtained by manual methods, but most of them are obtained with multifrequency ionosphere recorders of the type which the Bureau has had in operation since May, 1933. The critical frequency and virtual height data are supplemented by transmission data obtained by continuous automatic field-intensity records of reception from a number of U. S. and foreign high-frequency stations. By studying these two types of data together the Bureau is able to identify the layer by which long-distance propagation occurs at a given time, and to compute the best usable frequencies for long-distance transmission.

The data indicate that long-distance transmission at the higher frequencies is chiefly by way of the F layer at night both summer and winter and during the daytime in winter, but is usually by way of the E layer for distances of about 500 to 1,700 kilometers for several hours during the middle of the summer day, and by the F_2 layer for other hours and distances in the daytime in summer.

Beginning with March, 1937, graphs of critical frequencies and virtual heights have been separated into two groups, one for the condition in which the ionosphere is quiet or undisturbed, and the other for the condition in which the ionosphere is distrubed or stormy. On days when the ionosphere is stormy the virtual heights of the upper layers are higher, the critical frequencies are lower, and the absorption is greater, than on quiet days. All of these effects make for poorer transmission.

Each ionosphere storm lasts for a day or more and is manifested by a diffusion and instability in the upper layers of the ionosphere, and usually also by terrestrial magnetic activity.

Ionosphere storms were observed during 45 days of the period from January to September.

Sudden disturbances of the ionosphere, as indicated by radio fadeouts, were observed 131 times at Washington during January to September.

The long-time increase of critical frequencies of all the layers of the ionosphere, reported in previous papers, is continuing. This means that higher radio frequencies than have theretofore been useful are now practical for long-distance transmission. This effect is produced by the increasing solar activity which is manifested by increasing sunspot numbers. The sunspot cycle is expected to reach its maximum in 1938 or 1939, after which there will probably be a trend to decreasing critical frequencies and fewer ionosphere storms.

ULTRAVIOLET SOLAR RADIATION INTENSITIES IN THE STRATOSPHERE.

During the past year a novel apparatus has been used by W. W. Coblentz and R. Stair in measuring the total intensity of the ultraviolet of extremely short wave lengths in sunlight, at various heights above the earth's surface.

Aside from the scientific value of such information, the application of which cannot be foreseen, from a purely utilitarian standpoint the investigation of this question is of importance because of the need of such information in connection with problems in heliotherapy.

The type of meter (consisting of a photoelectric cell and filters) used in measuring the ultraviolet solar radiation intensities in the stratosphere, is similar to that employed in making measurements on the earth's surface. The primary difference is in the substitution of a photoelectrically controlled audio-frequency generator for the balanced amplifier and microammeter.

This ultraviolet intensity meter and a suitable radio-transmitter are transported aloft by means of unmanned balloons. The frequency of the radio-wave emitted is modulated by the response of the photoelectric cell, which response is proportional to the intensity of the incident ultraviolet rays. The height of the balloons is indicated by

means of a barometric pressure device as used in the radiobarograph developed in the Bureau's radio section, the signals, giving the altitude of the balloons, and the ultraviolet intensities, being received and recorded graphically at the ground station.

In this connection it is interesting to recall how, within the past few years, radio wave transmitting apparatus has become a very useful auxiliary means of recording meteorological data. Nowadays, the measurements of temperature, humidity, barometric pressure, and in the present instance, ultraviolet solar intensity, are transmitted from aloft by means of radio waves and are received and recorded in a central station on the ground, coincident with the time of observation. No lives are hazarded; and if the balloons and measuring apparatus are not recovered, at least the observations are on record and the undertaking is not a complete loss. As a matter of fact, in the ultraviolet program, using 3 instruments 6 flights were made, and to date 2 instruments have been returned.

The balloon ascensions were made during the last part of June and the first part of July, 1937. Altitudes up to 80,000 ft. were attained; but owing to the weakness of the radiosignal and the interference by noise, strictly quantitative data were obtained only 60,000 ft. (18 km.).

From this preliminary survey, the method appears promising for obtaining valuable scientific data on the altitude and extent of the ozone layer, and the ultraviolet solar intensity in the stratosphere, which information is of especial interest preceding and during a radio fade-out.

MEASUREMENT OF FLUCTUATIONS OF AIR SPEED IN TURBULENT FLOW.

Further advances in the knowledge of the flow of air are dependent to a large extent on experimental investigations of the character and magnitude of the fluctuations of the air speed in turbulent flow about its mean value. W. C. Mock, Jr. of the Bureau's Aerodynamics Section in cooperation with the National Advisory Committee for Aeronautics, has developed suitable apparatus and made several investigations of this character.

The apparatus generally used for the measurement of air speed fluctuations is the hot-wire anemometer, consisting of a small electrically heated platinum wire placed in the air stream to be investigated. Fluctuations of the speed of the air flowing past this wire produce fluctuations of its temperature, and hence of its electrical resistance. These resistance fluctuations in turn cause corresponding changes in the voltage drop across the wire which, by means of suitable apparatus, may be measured and interpreted in terms of air speed fluctuations. Because of the small magnitude of the air speed fluctuations, the resistance, and hence the voltage changes are very small and means must be provided for amplifying them before they can be measured. For this purpose vacuum tube amplifiers are used.

In the past the amplifiers used have generally been battery powered because of the comparative ease with which suitable performance could be obtained. Within the last two years, however, a suitable amplifier powered by rectified alternating current has been designed, built, and placed in operation at the Bureau. This apparatus represents a considerable improvement over previous equipment in respect to stability, ease of operation, and ease of maintenance. Technical Report 598 just published by the National Advisory Committee for Aeronautics, describes this new equipment in detail and presents data useful to those interested in the construction of similar apparatus.

CHEMICAL CONSTITUTION OF PETROLEUM.

The following is a review of a paper by Frederick D. Rossini to be presented at the annual meeting of the American Petroleum Institute, at Chicago, Ill., November 10–12, 1937:

Though investigations on the nature of petroleum have been going on for many decades, it was not until about 20 years ago that the petroleum industry itself began to consider seriously the chemical constitution of its raw material. With a few notable exceptions, the researches on the composition of petroleum had been sporadic and casual, and, relative to the importance, magnitude, and complexity of the problem, narrowly limited in scope. A dozen years ago, there were a

number of hydrocarbons the presence of which in the gasoline fraction of petroleum was reported, but for molecules of more than five carbon atoms the evidence was in most cases based upon the products obtained by chemical treatment of certain petroleum fractions or upon volume peaks in the distillation curve. What was needed was a comprehensive and unified investigation of the chemical constituents based upon the actual isolation of pure hydrocarbons from the crude oil.

The work on the chemical constitution of petroleum at the National Bureau of Standards was actually begun in 1926 by the late Edward W. Washburn on a modest scale as a project of the Bureau itself. In 1927, the work attracted the interest of the sponsors of the fundamental research program of the American Petroleum Institute, and the API Research Project 6 was established to carry on this coöperative research for the two institutions. Two points were considered important in formulating the research program for the Project: First, the study was to be complete on one representative crude petroleum, so that the results would have a quantitative as well as a qualitative significance; second, the work was to be carried out on such a quantity of the crude petroleum that, after its exhaustive separation, the fractions obtained would be substantially pure hydrocarbons in such quantity as to permit purification and accurate determination of all the important physical properties.

The following methods of fractionation, with the indicated variations, are employed in separating the natural mixture of hydrocarbons: (1) distillation, at one or more pressures, or on addition of an appropriate azeotrope-forming substance; (2) crystallization, by simple refrigeration with equilibrium melting, or by refrigeration in an appropriate solvent; (3) extraction, with one or more solvents, at different temperatures; (4) adsorption, with one or more adsorbents. In addition to those methods, carefully controlled sulfonation is sometimes used for fractionating mixtures of aromatic hydrocarbons.

After a substantially pure compound has been separated from petroleum, most, but usually not all, of the following properties are determined for record and identification:

Boiling point, freezing point, density, refractive index, molecular weight, carbon and hydrogen composition, critical solution temperature in aniline, viscosity, infrared (1 to 2) absorption spectrum, refractive dispersion, optical rotation, and photomicrographs of the crystals.

The present report discusses the foregoing processes of fractionation and methods of identification, and reviews the work which has so far been done by the Project on a Mid-continent petroleum. It is pointed out that from the material normally boiling below 180° C., there have been separated 45 different hydrocarbons (24 paraffins, 11 naphthenes or cycloparaffins, and 10 aromatics). Of that part of the petroleum boiling below 145° C., it is estimated that over three-fourths has been assigned to pure compounds, and of the material boiling between 145° and 180° C. over one-third. These various data on the gasoline fraction, together with the results which the Project has obtained to date on the lubricant fraction of this petroleum, are summarized in detail. The report concludes with an account of the problems at present under investigation and of those to be carried out in the future, and a discussion of the importance to the industry of these and allied researches.

SERVICE-TESTS OF TITANIUM-TREATED AND SILICON-TREATED STEEL RAILS.

The results of a coöperative investigation of the effects of titanium treatment on the properties of rail steel were published by the Bureau in 1923, as Technologic Paper T241. One thousand tons of rails from both the titanium-treated heats and from comparison silicon-treated heats were laid in the tracks of the Illinois Central Railroad Company (now the Illinois Central System) in 1921 for service tests.

Information about these rails obtained recently from the Illinois Central System is given in RP1042 by G. Willard Quick, in the Journal of Research for November. During fifteen years' service in heavy traffic, 52.5 percent of titanium-treated rails were removed for various reasons, whereas, 64.5 per cent. of the comparison silicon-treated rails were removed.

VIBRATED CONCRETE.

Up to 30 years ago concrete was mixed very dry, and tamped into place. Modern industrial trends of quantity production, such as the development of the chute conveyer, led to the general use of a very wet concrete that could be poured into the form and the form filled with but little subsequent working upon the concrete. Studies carried out in the decade starting with this transition, coupled with the service results of sloppy concretes, showed that not only does increase in the mixing water lower the strength of the concrete, but the additional water seriously decreases the durability.

Within recent years a reversal was slowly begun, and various methods have been introduced that permit decrease in the water content of the concrete.

About 1926 commerical vibrators were developed which made possible the use of drier concretes. Vibration has, therefore, come into more general use.

In studying this subject, John Tucker, Jr., chief of the Bureau's section on cement and concreting materials, has found that there is an optimum grading for concrete that is to be placed without vibration. If the least quantity of water be used that will permit placement without vibration, then vibration will cause segregation. On the other hand, vibration will not cause appreciable segregation if the concrete is made very dry, or if the mix is properly designed. The studies indicate that when the mortar content does not exceed the voids in the large aggregate by more than approximately 15 per cent., the segregation may be minimized. The segregation may be eliminated by making the concrete extremely dry—too dry for use in building construction, but satisfactory for making concrete building units, such as cast stone.

Vibration will increase the strength of the concrete above that of normally rodded specimens if the mix is very dry; the drier the mix, the greater the increase in strength. One year after making, the driest vibrated specimens showed a considerable increase in strength over the rodded specimens. The earlier the test age, however, the greater the strength increase due to vibration.

A complete account of this investigation will be published as RP1048 in the November number of the *Journal of Research*.

STRESS-STRAIN CHARACTERISTICS OF WOOL.

The classical view of protein structure is that the protein molecule is a polypeptide composed of a series of amino acids united through their carboxyl and amino groups. In the case of wool and similar materials, recent X-ray studies have indicated that these polypeptides lie parallel to the fiber axis and are held together by a variety of cross-linkages of the covalent and electrovalent types. That the bulk of the covalent cross-linkages in wool are the disulfide groups of the amino acid, cystine, is at the present time generally accepted. However, little is known about the nature of the electrovalent forces. The results of studies by Arnold M. Sookne and Milton Harris, on the extensibility of wool fibers are reported in the *Journal of Research* for November (RP1043), for the purpose of further elucidating the nature of the electrovalent linkages in wool.

The paper includes a description of an apparatus for studying the extensibility characteristics of single wool fibers, and gives data on the effects of the tanning (quinone), dyeing, and deamination processes, and of neutral salts on the extensibility of the wool fibers. The results indicate that the extensibility of the fibers is governed, for the most part, by factors which influence the swelling or hydration of the protein. Salt linkages of the type which might be formed by an attraction between the free amino and carboxyl groups in wool do not appreciably contribute to the physical stability of the fiber in aqueous solutions.

Addition to Bromine Plant.—(*Manufacturers Record*, Vol. CVI, No. 9.) As the motorist watches the filling station attendant fill his tank with the reddish-brown liquid which indicates he is receiving a tetraethyl-lead treated gasoline, he in most cases little realizes that the fuel has figuratively received a "shot" of sea water to pep it up. Bromine, into which the ethylene di-bromine is converted for combination with tetraethyl lead, has been extracted from the waters of the sea since 1934 at Kure Beach, 17 miles south of Wilmington, N. C. It is the only plant in the world for the removal of bromine from sea water. The steady rise in the consumption of leaded anti-knock gasoline in America has resulted in an expansion of the plant which will raise to 137,000 gallons per minute its capacity for processing the salty waters. To carry out this chemical enterprise it is necessary to treat 2,000 gallons of water to obtain one pound of bromine which forms 85 per cent. of the ethylene di-bromine solution.

R. H. O.

V.
19

THE FRANKLIN INSTITUTE.

MONTHLY MEETING, NOVEMBER 17, 1937.

The regular monthly meeting was called to order at 8:30 o'clock by Mr. Walton Forstall, Vice-President.

The minutes of the previous meeting were approved as published in the November issue of the Journal.

The Secretary announced that the additions to membership since the last meeting were as follows:

Institute Members	12
Museum Members	30
Total	42

He also called attention to the James Mapes Dodge series of Christmas week lectures for the young which will be held on the afternoons of December 27, 28 and 29. Dr. Dayton C. Miller of Cleveland, Ohio, will speak on "Electrostatics."

The Chairman then introduced the speaker of the evening, Dr. C. E. K. Mees, Vice-President, Eastman Kodak Company, who spoke on "Recent Progress in Astronomical Photography."

The speaker pointed out that in spite of the fact that astronomical observation is carried out almost entirely by means of photography, the materials used for astronomical work were, until recently, selected from those available commercially and intended primarily for other purposes. During recent years, however, special materials for astronomical purposes have been placed on the market which have made it possible for the observer to select those which have properties suitable for the special work which is being undertaken.

Photographic materials differ in sensitivity, contrast and graininess. By the preparation of many new sensitizing dyes, it has been possible to prepare materials which are sensitive to all parts of the visible spectrum and far into the infra-red. The application of these materials has been of great value in practical astronomical work.

The paper was illustrated by many lantern slides, a moving picture film showing the gases which surround the sun and several pictures relating to the solar eclipse of the past Summer.

After a spirited discussion, a rising vote of thanks was tendered the speaker.

Adjourned.

HENRY BUTLER ALLEN,
Secretary.

RESOLUTIONS PASSED BY THE BOARD OF MANAGERS ON THE OCCASION OF THE DEATH OF MR. HENRY HOWSON, VICE-PRESIDENT.

Resolved, That as Managers of The Franklin Institute of the State of Pennsylvania we record this expression of sorrow in the death of our beloved fellow-manager, Mr. Henry Howson, who departed this life on the fifth of July, 1937, at the age of seventy-nine years.

Rarely endowed through parentage, culture and associations as an outstanding adviser in legal-technical matters, during the fifty-six years of his membership in this institution he served as one of this Board as well as Vice-President; and due entirely to his sound perceptions and excellent judgment as Chairman of various committees established for the welfare and betterment of The Franklin Institute; his consideration, generosity and lovable personality won him the profound admiration and confidence of all his associates; be it further

Resolved, That the Board of Managers of The Franklin Institute of the State of Pennsylvania, of which Mr. Howson was a member since 1881, in his death have suffered an immeasurable loss in respect to his acumen and guidance and value as a member of this Board, in attestation of which this Board of Managers does here record as best it may this Minute to his memory and honour, engrossed copies of which are hereby ordered to be presented by this Board to the members of Mr. Howson's family.

October 20, 1937.

LIBRARY NOTES.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesday and Thursdays two until ten o'clock P. M. 602 readers made use of the facilities during the twenty-six days of October.

RECENT ADDITIONS.

Agriculture and Forestry.

BROWN, NELSON COURTLANDT. Timber Products and Industries. The Harvesting, Conversion, and Marketing of Materials Other than Lumber, including the Principal Derivatives and Extractives. 1937.

Architecture and Building.

Association of American Railroads. Mechanical Division. Car Builders' Cyclopedia of American Practice. Fourteenth Edition. 1937.

BEACH, W. W. The Supervision of Construction. 1937.

Astronomy.

MCVITTIE, G. C. Cosmological Theory. 1937. Methuen's Monographs on Physical Subjects.

Biology and Biochemistry.

MCCLUNG, C. E., Editor. Handbook of Microscopical Technique for Workers in Animal and Plant Tissues. Second Edition, Revised and Enlarged. 1937.

Royal Society of London. Philosophical Transactions. Series B. Volume 227. 1937.

Chemistry and Chemical Technology.

ADKINS, HOMER. Reactions of Hydrogen with Organic Compounds over Copper-Chromium Oxide and Nickel Catalysts. 1937.

BURK, ROBERT E., AND OTHERS. Polymerization and its Applications in the Fields of Rubber, Synthetic Resins, and Petroleum. 1937. American Chemical, Society, Monograph Series. No. 75.

GETMAN, FREDERICK H. Outlines of Theoretical Chemistry. Sixth Edition by Farrington Daniels. 1937.

HAHN, OTTO. Applied Radiochemistry. 1936. The George Fisher Baker Non-Resident Lectureship in Chemistry at Cornell University. Volume 14.

Jahresbericht über die Leistungen der chemischen Technologie für das Jahr 1936. 82 Jahrgang. 2 Abteilung: Organischer Teil. 1937.

KRAUSE, HUGO. Metallfärbung. Die wichtigsten Verfahren zur Oberflächenfärbung und zum Schutz von Metallgegenständen. Zweite, vollständig neu bearbeitete und vermehrte Auflage. 1937.

PANETH, FRITZ. Radio-Elements as Indicators and Other Selected Topics in Inorganic Chemistry. 1928. George Fisher Baker Non-Resident Lectureship in Chemistry at Cornell University. Volume 2.

PARTINGTON, J. R. A Text-Book of Inorganic Chemistry for University Students. Fifth Edition. 1937.

PIERCE, WILLIS CONWAY, AND EDWARD LAUTH HAENISCH. Quantitative Analysis. 1937.

RIEGEL, EMIL RAYMOND. Industrial Chemistry. An Elementary Treatise for the Student and General Reader. Third Edition. 1937.

ROGERS, FRANCES, AND ALICE BEARD. 5000 Years of Glass. 1937.

SCHWAB, GEORG-MARIA. Catalysis from the Standpoint of Chemical Kinetics. Translated from the First German Edition, with Additions from the Recent Literature by the Author, by Hugh S. Taylor and R. Spence. 1937.

TREADWELL, F. P. Analytical Chemistry. Translated and Revised by William T. Hall. Volume 1: Qualitative Analysis. Ninth English Edition. 1937.

WALKER, WILLIAM H., AND OTHERS. Principles of Chemical Engineering. Third Edition, Revised and Rewritten. 1937.

Wetting and Detergency, Scientific and Technical Aspects. Being the Papers Presented at a Symposium Held in London, Feb. 19th–20th, 1937, under the Auspices of the British Section of the International Society of Leather Trades' Chemists. With a Foreword by W. Clayton. 1937.

Electricity and Electrical Engineering.

LAWRENCE, RALPH R. Principles of Alternating Current Machinery. Second Edition. 1921. Electrical Engineering Texts.

LAWRENCE, RALPH R. Principles of Alternating Currents. Second Edition. 1935. Electrical Engineering Texts.

MCARTHUR, E. D. Electronics and Electron Tubes. 1936.

MAXWELL, JAMES CLERK. Origins of Clerk Maxwell's Electric Ideas as Described in Familiar Letters to William Thomson. Edited by Sir Joseph Larmor. 1937.

PIDDUCK, F. B. Lectures on the Mathematical Theory of Electricity. 1937.

RAMSEY, R. R. Experimental Radio. Fourth Edition. 1937.

SIEMENS-WERKE. Wissenschaftliche Veröffentlichungen. XVI Band, zweites Heft. 1937.

STAFFORD, H. E. Troubles of Electrical Equipment: their Symptoms, Causes and Remedy. First Edition. 1937.

USSR Academy of Sciences. Krzizhanovsky Power Institute. Electric Power Development in the USSR. 1936. USSR Committee for International Scientific and Technical Conferences.

VIEWEG, R., Editor. Elektrotechnische Isolierstoffe. Entwicklung, Gestaltung. Verwendung. 1937.

WRIGHT, CHARLES ALLEN. Telephone Communication with Particular Application to Medium-Frequency Alternating Currents and Electromotive Forces. First Edition. 1925.

Engineering.

FIFE, WALTER MAXWELL, AND JOHN BENSON WILBUR. Theory of Statically Indeterminate Structures. First Edition. 1937.

Manufactures.

VALKÓ, EMMERICH. Kolloidchemische Grundlagen der Textilveredlung. 1937.

Marine Engineering.

Audel's New Marine Engineers' Guide. A Practical Treatise on Marine Engines, Boilers and Auxiliary Machinery. 1937.

Mathematics.

EUKLID. Die Elemente. Nach Heibergs Text aus dem Griechischen übersetzt und herausgegeben von Clemens Thaer. v Teil. 1937. Ostwald's Klassiker der exakten Wissenschaften Nr. 243.

KESTELMAN, H. Modern Theories of Integration. 1937.

Mechanical Engineering.

BARRITT, J. W. Machine Shop Operations. No date.

KELLER, CURT. The Theory and Performance of Axial-Flow Fans. Adapted to the Use of Fan Designers by Lionel S. Marks with the Assistance of John R. Weske. First Edition. 1937.

MARSHALL, E. G. Practical Die Design and Die Making. First Edition. 1937.

STEINER, KALMAN. Oil Burners. First Edition. 1937.

THOMSEN, T. C. The Practice of Lubrication. An Engineering Treatise on the Origin, Nature and Testing of Lubricants, their Selection, Application and Use. Third Edition. 1937.

Meteorology.

BYERS, HORACE ROBERT. Synoptic and Aeronautical Meteorology. First Edition. 1937.

Photography.

FRAPRIE, FRANK R., AND FLORENCE C. O'CONNOR. Photographic Amusements Including Tricks and Unusual Novel Effects Obtainable with the Camera. Eleventh Edition, Revised and Enlarged. 1937.

Photographie 1938.

U. S. Camera 1937.

Physics.

EVERETT, H. A. Thermodynamics. A Course Developed for Students in Engineering Colleges. 1937.

LANDÉ, ALFRED. Principles of Quantum Mechanics. 1937.

ROBERTSON, JOHN KELLOCK. Atomic Artillery. Modern Alchemy for Everyman. 1937.

Wien-Harms Handbuch der Experimentalphysik. Band 26: Astrophysik, herausgegeben von B. Strömgren. 1937.

WINSTON, STANTON E. Thermodynamics. A Practical Text, Covering the Fundamentals of Thermodynamics that are basic to the Engineering Field. 1937.

ZEMANSKY, MARK W. Heat and Thermodynamics. An Intermediate Textbook for Students of Physics, Chemistry, and Engineering. First Edition. 1937.

Railroad Engineering.

BLACK, ARCHIBALD. The Story of Tunnels. 1937.

Scientific Essays.

GUNTHER, R. T. Early Science in Oxford. Volume XI: Oxford Colleges and their Men of Science. 1937.

Sugar.

MEYER, H., Editor. Das Goldene Buch des Süsswarengewerbes. Fachkalender 1937.

Sugar Reference Book and Directory. 1937.

BOOK REVIEWS.

ORIGINS OF CLERK MAXWELL'S ELECTRIC IDEAS, as described in familiar letters to William Thomson, edited by Sir Joseph Larmor. 56 pages, illustrations, 18 × 26 cms. Cambridge, The University Press, 1937. Price $1.00.

The letters printed in this book have emerged among Lord Kelvin's manuscript remains. They cover the period February 20, 1854, to September 1, 1879, and are addressed to Maxwell's scientific friend William Thomson. In them there is given an account of the genesis and rapid progress of Clerk Maxwell's ideas as he groped toward a structural theory of the electric and magnetic field. The letters were originally issued as Part V of the Volume 32 of the proceedings of the Cambridge Philosophical Society. Because they may interest a larger circle they are made available in the form of this book.

R. H. OPPERMANN.

INDUSTRIAL CHEMISTRY, an elementary treatise for the student and general reader, by Emil Raymond Riegel. Third edition, 851 pages, plates, illustrations, tables, 15 × 23 cms. New York, Reinhold Publishing Corporation, 1937. Price, $5.75.

Evidences of the continual increase of new methods and articles of manufacture in the chemical industries are, today, on every hand. Industrial research

laboratories have, it seems, reached a success hitherto unheard of both in quantity production in things new as well as in quality production in improving older processes and materials. The laboratory and its research work is now an absolute necessity. So great has been the actual application of the output of the industrial chemical research laboratory that a book on this subject written only a few years ago needs to be revised in the light of present day practice. Some of the new developments and practices are basic which requires them to be given equal weight with the older and more well known developments.

The author of this book, in recognizing these facts, has published his third edition of this well known work. The book is divided into some fifty chapters each on a definite chemical indstry and each including the fundamental principles brought up to present day practice. Among these can be noted the production of bromine from sea water, neoprene, architectural glass, the addition of columbium in stainless steels, indium addition to silver and many others. There is a chapter devoted to patent law as well as others on chemical machinery such as pumps, filters, crushers, materials used by the chemical engineer including the making of iron castings, instruments of control etc. One of the most interesting parts of the book is that devoted to synthetic and semi-synthetic organic chemicals. A family tree is presented of ethylene and its derivatives, and there is a table of synthetic organic chemicals and another listing some catalytic reactions of industrial importance. Resins and plastics are especially given an up to date treatment. The author, in the preface, makes special mention to tables of figures on production, either in units of weight or in money value or both, which are given for the year 1935, the latest published by the Bureau of the Census. He states in this connection that the next figures will be for 1937 and will not appear until late in 1938.

The book is written in an exceptional manner. While it is essentially a compilation of a great mass of data, it is not so jammed in that reading and understanding are difficult. At the end of each chapter there are given problems for the student, patent references and reading references for those wishing further data. These are in addition to the many reference footnotes throughout the text. A very good subject index makes the book invaluable for reference.

R. H. OPPERMANN.

EXPERIMENTAL RADIO, by R. R. Ramsey. Fourth edition, 196 pages, illustrations, 15 × 23 cms. Bloomington, Indiana, Ramsey Publishing Company, 1937. Price $2.75.

This book is in its fourth edition, the first having been published in December 1922. It is not a text, as a matter of fact, some knowledge of fundamental electricity is needed before one can use it. The book is a description of how to perform some 132 experiments. They range from experiments on how to test batteries, the construction of measuring instruments and their use, to the calculation and measurements of various radio circuits and apparatus. All of them are of a simple fundamental nature especially designed so as to impress upon the experimenter the method of obtaining and the meaning of the results. The list is built up from the simple to the more complex and the experimenter will find, after progressing to some extent through the book, that aside from the practical knowledge gained, some very useful apparatus has been constructed which is used

in later experiments. Another feature noteworthy is that a minimum of expenditure of money is necessary for materials. There is an absence of the use of higher mathematics.

The book should have a wide field of usefulness. This includes students, electrical experimenters, radio amateurs, and those with just a smattering of electrical knowledge about equal to what may be obtained from an elementary course in physics. It offers an opportunity to gain a clear conception of the properties and characteristics of electric and radio circuits.

R. H. OPPERMANN.

COSMOLOGICAL THEORY, by G. C. McVittie. 103 pages, illustrations, 17 × 10 cms. London, Methuen & Co. Ltd., 1937. Price 2s, 6d.

This little book is one of a series "intended to supply readers of average scientific attainment with a compact statement of the modern position in each subject." The subject under discussion here is that branch of physics which deals with the structure of matter in its most bulky and massive state, the whole physical universe being regarded as a single system. To accomplish the purpose as set forth, the author has done remarkably well, particularly so, when it is realized that there are only 100 pages to the book.

The exposition begins with observational material of the extra-galactic nebulæ, certain faint telescopic objects some of which can be resolved into separately visible stars surrounding what appears to be a mass of glowing gas. Next, an acquaintance is made with the tensor calculus and with generalized differential geometry, followed by a brief sketch of the principles of general relativity and an investigation of the extent to which these principles can be used to give a theory of the universe as a whole. At this point interesting hypotheses are formed. There is indicated that the volume of space surveyed is a small fraction of the whole. But whether this is due to space being hyperbolic or whether it is because space is spherical but of very large radius, are questions "which cannot yet be answered with certainty."

The last chapter of the book is devoted to Professor E. A. Milne's kinematical theory of the universe and it shows the meaning of distance on the process of measurement. It gives a simpler interpretation of co-ordinates than does general relativity.

The author certainly accomplishes what he has set out to do. To those mentally equipped, the work should certainly be interesting.

R. H. OPPERMANN.

INTRODUCTION TO PHYSIOLOGICAL OPTICS, by James P. C. Southall. 426 pages, plates, illustrations, 16 × 25 cms. New York, Oxford University Press, 1937. Price $5.50.

As is implied by the title, this book is only an introduction to the subject. It is, however, in reality more than that, for its purpose is not just an introduction in the sense that it furnishes a stepping stone for the utilization of certain prepared knowledge in a sequence of studies toward a specialized end, but it opens a field of interesting study for all those possessing an average level of knowledge of a general nature. In other words, the book is intended as an introduction for readers of many diversified interests, instructive "to a large class of intelligent laymen

who in different degrees and from various motives are desirous of obtaining such knowledge as is within their reach concerning the dioptrics of the eye and the sense of sight." To write a book to fit in this many-sided niche is extremely difficult. How well it is done can be seen by examination of it.

The work is opened by a treatment on the organ of vision wherein the sense of sight is explained together with the structure of the eye and the operation of the seeing process. An elementary theory of optical imagery prepares for the further study of the optical system of the eye by defining explicitly some of the terms and explaining some of the nomenclature and symbols. A chapter on correction eye-glasses first gives some history of spectacles from the middle ages, then proceeds to describe why and how correction is affected. The nature of hyperopia, myopia and astigmatism, the kinematics of the mobile eye, the nature of binocular vision, color vision and its theories, the temporal and spatial reactions of the organ of vision are subsequently explained.

To achieve the aims of the book it was necessary that it be written in a generally understandable language and the construction had to be such as not to be too difficult to follow. The author has done this remarkably well, although in one or two instances it seems that he has become a little too zealous. These are not sufficient to cause a serious drawback however. Certain sections of the topic, of course, can involve considerable use of mathematics but the author is probably at his best here for he gives an admirable exposition using only very elementary geometry and algebra.

A very carefully prepared subject index is included which adds greatly to the value of the book for reference purposes. There should be considerable demand for the book for it accomplishes its purpose very well.

R. H. OPPERMANN.

POLYMERIZATION AND ITS APPLICATIONS IN THE FIELDS OF RUBBER, SYNTHETIC RESINS, AND PETROLEUM, by Robert E. Burk, Howard E. Thompson, Archie J. Weith and Ira Williams. 312 pages, illustrations, tables, 16 × 23 cms. New York, Reinhold Publishing Corporation, 1937. Price $7.50.

The purposes of the American Chemical Society's Monographs are well known and it is sufficient to say that the subjects chosen for this series hold the importance to warrant enlightened attention. Polymerization, especially in recent years, is a subject that has come to the fore in more than one way. It is a theoretical field which directly underlies numerous practical problems and developments of today and there are indications that it will become of importance in other, as yet unknown, developments.

This monograph develops the subject from both the theoretical viewpoint of the mechanism of polymerization, and its bearing in the various industries. It starts out with formulating a correct and clear definition of polymerization and an explanation of principles. Present theories are discussed, and there are suggested ways of future progress. The work does not cover all applied fields in which polymerization is a factor. Only those fields where it plays an important part are considered.

The relation between molecular structure and the rate of polymerization is well presented. Here polymeric phenomena are divided into molecular associations and stable polymers. The greater interest is centered on the latter. Un-

saturation, conjugation, alkyl substitution, cyclic structures, and substitutions are well brought out. The mechanism of the structure is paramount. With regard to catalysis there is given a very useful table listing substances known to polymerize with catalysts, reaction conditions, and products. The kinetic approach to reaction mechanisms is then discussed, which gives a graphic notion of the way it occurs. The polymer structure is treated in considerable detail. In discussing the nature of liquids the viewpoint is primarily kinetic rather than that of structural organic chemistry.

The last three chapters of the book are devoted to the applications of polymerization in the rubber, synthetic resin, and the petroleum industry. Each of these may be taken as a representative review of the present state of our knowledge.

The work as a whole furnishes a well digested view of this important subject, backed up by a great mass of references suitably recorded.

R. H. OPPERMANN.

GUIDED ACTIVITIES IN SENIOR SCIENCE, by George L. Bush, Theodore W. Ptacek, and John Kovats, Jr. 251 pages, 19 × 24 cms. New York, American Book Company, 1937.

Here is a book that promises to be very valuable, not only in adding to one's store of knowledge but in encouraging the thinking process. It probably will be of much service to high school students or those with equivalent educational equipment. It is composed of what the authors call units, ten in number, each devoted to a commonly observed thing such as water, or fire, or safety. Following each unit title there is a brief elementary description or discussion on it. Under the title, "water," for instance, a brief mention is made of the impurities in water, the functions of water and the physical states that water may be observed. After this there is a list of very carefully prepared questions on the subject and room to write in the answers. The book may be used as a study exercise in conjunction with a high school course in general science.

R. H. OPPERMANN.

THE STRUCTURE AND COMPOSITION OF FOODS, by Andrew L. Winton and Kate Barber Winton. Volume III, Animal Products, 524 pages, tables, illustrations, 15 × 24 cms. New York, John Wiley & Sons, Inc., 1937. Price $8.00.

This is Volume III of a set of books on foods. It is devoted exclusively to foods of animal origin. Those whose interests lie in the field covered by this book will find here a volume just crammed full of useful data, constituting a broad survey of the subject, the result of what must have been a very exhaustive search through the technical literature coupled with an expert knowledge and writing ability.

The authors have divided the subject matter into three parts. The first is devoted to milk, and is further divided into the kinds of milk including milk from cows, goats, camels, mares, and humans. Under milk products there are parts on artificial milk, remade milk, evaporated milk, powders, malted milk, cheese, ice cream, etc. This division takes up the larger part of the book. It gives a great mass of physical and chemical data such as microscopic characters, specific gravity, electrical conductivity, and viscosity. The second part of the book is on

eggs, a somewhat less of a perfect food than milk. This explains the structure, color and composition of various kinds of eggs. Part three, the last part of the book treats on meats. It covers also poultry, fish, and shell fish, and contains in addition to tables showing the usual proximate analyses, ash analyses, and percentages of minor mineral constitutents, detailed descriptions of the proteins, fats, carbohydrates, meat bases, etc.

The book throughout contains innumerable tables of properties of various substances treated and where necessary the structural formula. The many references which were used to compile the book are all listed as footnotes. A comprehensive index is a feature that is well worth mention. The book should be of great value to workers in this great field.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Report No. 601. Torsion Tests of Tubes, by Ambrose H. Stang, Walter Ramberg, and Goldie Back. 21 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1937. Price ten cents.

Torsion tests of 63 chromium-molybdenum steel tubes and 102 17ST aluminum-alloy tubes of various sizes and lengths were made to study the dependence of the torsional strength on both the dimensions of the tube and the physical properties of the tube material. Three types of failure were found to be important for sizes of tubes frequently used in aircraft construction: (1) failure by plastic shear, in which the tube material reached its yield strength before the critical torque was reached; (2) failure by elastic two-lobe buckling, which depended only on the elastic properties of the tube material and the dimensions of the tube; and (3) failure by a combination of (1) and (2), that is, by buckling taking place after some yielding of the tube material.

An adequate theory exists for explaining failure by (1) or (2). Most of the tubes failed by the combined failure (3), for which a theoretical solution seems unattainable at this time. An analysis of the data showed that the torsional strength of these tubes could be expressed by an empirical formula involving only the tensile properties of the tube material in addition to the dimensions of the tube. Design charts were computed from this empirical formula and a number of examples were worked out to facilitate the application of the charts.

Report No. 605. Résumé and Analysis of N. A. C. A. Lateral Control Research, by Fred E. Weick and Robert T. Jones. 27 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1937. Price fifteen cents.

An analysis of the principal results of recent N. A. C. A. lateral control research is made by utilizing the experience and progress gained during the course of the investigation. Two things are considered of primary importance in judging the effectiveness of different control devices: The (calculated) banking and yawing motion of a typical small airplane caused by a deflection of the control, and the stick force required to produce this deflection. The report includes a table in which a number of different lateral control devices are compared on these bases.

Experience gained while testing various devices in flight with a Fairchild 22 airplane indicated that, following a sudden deflection of the control at low speed,

an angle of bank of 15° in 1 second represented a satisfactory minimum degree of effectiveness for this size of airplane. Some devices capable of giving this degree of control were, however, considered to be not entirely satisfactory on account of sluggishness in starting the motion. Devices located near the trailing edge of the wings had no detectable sluggishness. Lateral control forces considered desirable by the test pilots varied from 2 to 8 pounds; 15 pounds was considered excessive.

Test flights demonstrated that satisfactory lateral control at high angles of attack depends as much on the retention of stability as on aileron effectiveness.

The aerodynamic characteristics of plain sealed ailerons could be accurately predicted by a modification of the aerodynamic theory utilizing the results of experiments with sealed flaps. Straight narrow-chord sealed ailerons covering 60 to 80 per cent. of the semispan represented about the most efficient arrangement of plain unbalanced ailerons from considerations of operating force. The stick force of plain ailerons can be effectively reduced by the use of a differential linkage in conjunction with a small fixed tab arranged to press the ailerons upward.

Report No. 606. Electrical Thermometers for Aircraft, by John B. Peterson and S. H. J. Womack. 16 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1937. Price ten cents.

Electrical thermometers commonly used on aircraft are the thermoelectric type for measuring engine-cylinder temperatures, the resistance type for measuring air temperatures, and the superheat meters of the thermoelectric and resistance types for use on airships. These instruments are described and their advantages and disadvantages enumerated. Methods of testing these instruments and the performance to be expected from each are discussed. The field testing of engine cylinder thermometers is treated in detail.

PUBLICATIONS RECEIVED.

Sunspots and Their Effects, by Harlan True Stetson. 201 pages, plates, illustrations, 14 × 21 cms. New York, McGraw-Hill Book Company, Inc., 1937. Price $2.00.

Exploring the Heavens, by Clyde Fisher. 223 pages, plates, illustrations, 14 × 22 cms. New York, Thomas Y. Crowell Company, 1937. Price $2.50.

Chemical Engineering Catalog, 1937, Twenty-Second Annual Edition. The Process Industries' Catalog, 1034 pages, illustrations, 20 × 28 cms. New York, Reinhold Publishing Corporation.

Canada Department of Mines and Resources, Mines and Geology Branch, Bureau of Mines. Investigations in Ore Dressing and Metallurgy, July to December, 1936. 204 pages, tables, illustrations, 16 × 25 cms. Ottawa, Printer to the King's Most Excellent Majesty, 1937.

National Research Council, Transactions of the American Geophysical Union, Eighteenth Annual Meeting, April 28, 29, 30, 1937. Denver, Colorado. Part I, Reports and Papers, Washington, D. C., General Assembly and Sections of Geodesy, Seismology, Meteorology, Terrestrial Magnetism and Electricity, Oceanography, and Volcanology. 264 pages, illustrations, tables. Part II, Reports and Papers, Section of Hydrology and South Continental Divide Snow-

Survey Conference. 397 pages, illustrations, tables. Two volumes, 17 × 25 cms. Washington, National Research Council of The National Academy of Sciences, 1937.

National Advisory Committee for Aeronautics. Technical Notes: No. 616, The Measurement of Air Speed of Airplanes, by F. L. Thompson. 24 pages, illustrations. No. 617, Stability of Structural Members Under Axial Load, by Eugene E. Lundquist. 29 pages, tables, illustrations. No. 618, Increasing the Strength of Aluminum-Alloy Columns by Prestressing, by M. Holt and E. C. Hartmann. 12 pages, tables, illustrations. No. 620, Energy Loss, Velocity Distribution, and Temperature Distribution for a Baffled Cylinder Model, by Maurice J. Brevoort. 36 pages, tables, illustrations. 4 pamphlets, 20 × 26 cms. Washington, Committee, 1937.

A Yearbook of Railroad Information, 1937 Edition, 96 pages, tables, illustrations, 10 × 15 cms. New York, Committee on Public Relations of the Eastern Railroads.

Canada Department of Trade and Commerce, Dominion Bureau of Statistics, Transportation Branch. Preliminary Report on Statistics of Steam Railways in Canada, 1936. 10 pages, tables, 22 × 28 cms. Ottawa, Minister of Trade and Commerce, 1937. Price 10 cents.

Social Security Board, Bureau of Research and Statistics, Division of Public Assistance Statistics. Current Statistics of Relief in Rural and Town Areas for June–July 1937 and for the years 1932–1936. Volume 2, No. 7, issued October 1937. 11 pages, tables, illustrations 20 × 27 cms. Washington, U. S. Government Printing Office, 1937.

Facts to Consumers, 18 pages, illustrations, 9 × 16 cms. New York, Electrical Testing Laboratories, September 1937.

U. S. Department of Commerce, National Bureau of Standards, Research Paper RP1023, Part of Journal of Research of the National Bureau of Standards, Volume 19, September 1937. 12 typewritten pages, tables, illustrations, 15 × 23 cms. Washington, Superintendent of Documents. Price 5 cents.

ERRATA.

LAW OF SIZE DISTRIBUTION AND STATISTICAL DESCRIPTION OF PARTICULATE MATERIALS.

BY

PAUL S. ROLLER.

May, 1937, Volume 223, page 609.

Page 613, line nine, formulæ (11), 2.303, should read $\frac{1}{2.303}$.

Line sixteen, 2.303b, should read $\frac{1}{2.303b}$. Page 624, Table Ic, order of hydrated limes, should read 1, 2, 3, 4, 5, beginning with 1, at the top.

CURRENT TOPICS.

World's Biggest Dredge.—(*Engineering News Record*, Vol. 119, No. 12.) The War Department's new hopper dredge, the Goethals, which was launched recently is the world's largest. Its overall length is 476 feet, loaded draft 25 feet and it has a hopper capacity of 5000 cubic yards. The dredge will work to a maximum cutting depth of 50 feet. Four boilers operating at 425 lb. pressure supply steam to turbo-electric generators. Two electric propelling motors are rated at 2250 hp., and two 32 in. dredging pumps are each driven by a 1300 hp. motor. The dredge is of the two compartment type, so that when fully loaded and with two compartments flooded the vessel will still float.

R. H. O.

Giant Hydraulic Press for Aircraft.—(*Iron Age*, Vol. 140, No. 12.) The Douglas Aircraft Co., Inc., Santa Monica, Cal., has installed what is said to be the largest high speed hydraulic press in the world. Used to accomplish several thousand production operations in the shaping and forming of parts for commercial transports, the press is self-contained with a pressure capacity of 5000 tons. The maximum opening between platen and bed is approximately 4 feet. The total pressing force is created by a single hydraulic ram 6 ft. in diameter. This is actuated by oil under a pressure of 2500 lb. per sq. in. Hydraulic pressure is generated by a battery of four large radial pumps of the variable-reversible-delivery type and these are direct-driven by two 150 hp. motors. The hydraulic power from these pumps is directly applied, without intervening valves, to the press rams. The speed and direction of press movements are thus controlled by regulation of the volume and direction of pump output. This makes possible high speed operation with absolute smoothness.

R. H. O.

Plywood.—In a twelve page pamphlet (No. 16), the National Lumber Manufacturers Association covers the whole subject of specifications for this valuable modern lumber product. There is a description of the product, its method of manufacture, and its guaranteed inspection under the Douglas Fir Plywood Association. There is a glossary of terms and abbreviations and a brief table of

recommended use items with the grades recommended for the best service, and the various thicknesses of the plywood commonly used for special purposes.

R. H. O.

Selected Bibliography of Engineering Subjects.—The Engineers' Council for Professional Development has recently published a list of books of college grade, chosen through consultation with a large group of experienced engineers and educators as worthy examples of the best in professional literature. It should be helpful in providing guidance to young engineers who wish to extend their academic training by further study either in familiar fields or in new ones.

R. H. O.

Fellowships for Advanced Study.—In order to improve the quality of education and the practice of the arts and professions in the United States, to foster research, and to provide for the cause of better international understanding, the John Simon Guggenheim Memorial Foundation offers a limited number of Fellowships, tenable under the freest possible conditions, for research in any field of knowledge and for creative work in any of the fine arts, including music. In the main, the Fellowships have been granted for work abroad; but for 1938–39, in exceptional cases, a limited number may be granted for work in the United States.

R. H. O.

Forest Fire Fighters Get Supplies in Parachutes.—The United States Department of Agriculture states that emergency parachutes made from pieces of burlap about six feet square have been used successfully by the Forest Service to drop food and other supplies from airplanes for men on remote fire fighting lines in the national forests. Large burlap sacks, used in bagging wool, generally are used to make the parachute. In one experiment nine dozen eggs were dropped 500 feet in one of the homemade parachutes and only two eggs were broken. Food in glass jars, canned milk, water, and even tools, have been dropped to aid the fighters. Such delivery saves much needed time in emergencies.

R. H. O.

INDEX TO VOLUME 224.

July to December, 1937.

Alber, Herbert K. & Josef Harand: The microchemical laboratory of the Bio-chemical Research Foundation, 729

Bancroft, Wilder D. & James E. Magoffin: The energy hump in chemistry I, II, 283, 475

Bio-chemical Research Foundation. The microchemical laboratory of (Alber & Harand), 729

Book Reviews:

Bishop, M.: Pascal, the life of genius, 127

Bragg, W. L.: Atomic structure of minerals, 252

Burk, R. E. & others: Polymerization, 796

Bush, G. L. & others: Guided activities in senior science, 797

Candler, A. C.: Atomic spectra and the vector model, 128

Compton, K. T. & others: Physics in industry, 406

Dantzig, T.: Aspects of science, 534

Dickinson, H. W.: Matthew Boulton, 125

Dow, Wm. G.: Fundamentals of engineering electronics, 404

Dunlap, O. E.: Marconi, the man and his wireless, 254

Edwards, J. D.: Aluminum paint and powder, 400

Egloff, G.: The reactions of pure hydrocarbons, 256

Epstein, D. S.: Textbook of thermodynamics, 531

Fermi, E.: Thermodynamics, 533

Gauss, C. F.: Inaugural lecture, 531

Ghirardi A. A.: Auto-radio trouble shooter "gadget"; Home-radio pocket trouble shooter "gadget," 534

Gray, G. W.: Advancing front of science, 533

Gunther, R. T.: Early science in Cambridge, 402

Gurney, R. W.: Ions in solution, 400

Haas, A.: Elementare Physik, 124

Haas, A.: The world of atoms, 126

Herzberg, G.: Atomic spectra and atomic structure, 126

Houwink, R.: Elasticity, plasticity, and structure of matter, 403

Jones A. T.: Sound, 405

Klinefelter, L. M.: Electrical occupations, 532

Landé, A.: Principles of quantum mechanics, 668

Langre, N. A.: Handbook of chemistry, 529

Langsdorf, A. S. Theory of alternating-current machinery, 528

Larmor, J., ed.: Origins of Clerk Maxwell's Electric Ideas, 793

Luckiesh, M. & F. K. Moss: The science of seeing, 668

McVittie, G. C.: Cosmological theory, 795

Michael, W.: Theorie der wechselstrommaschinen in vektorieller darstellung, 125

Morrison, A. C.: Man in a chemical world, 255

Muldoon, H. C.: A textbook of organic chemistry, 407

National Advisory Committee for Aeronautics, Report: No. 585, 257; No. 586, 670; No. 589, 258; No. 590, 258; No. 591, 405; No. 592, 670; No. 593, 406; No. 594, 671; No. 595, 406; No. 596, 530; No. 597, 671; No. 598, 530; No. 599, 259; No. 600, 672; No. 601, 798; No. 603, 672; No. 605, 798; No. 606, 799; No. 609, 673
Northrup, E. F.: Zero to eighty, 401
Outline of atomic physics, 399
Ramsey, A. S.: Electricity and magnetism, 256
Ramsey, R. R.: Experimental radio, 794
Read, J.: Prelude to chemistry, 253
Reilly, J.: Distillation, 257
Robertson, J. K.: Atomic artillery, 669
Roth, H.: Quantitative organic microanalysis of Fritz Pregl, 530
Rutherford, Lord: The newer alchemy, 255
Southall, J. P. C.: Introduction to physiological optics, 795
Van den Bergh, G.: Astronomy for the millions, 666
Waters, Wm. A.: Physical aspects of organic chemistry, 399
Williams, S. R.: Foundations of college physics, 667
Winton, A. L. & K. B.: Structure and composition of foods, vol. 3, 797

Carlson, Roy W.: Results of recent cement research and their partial application, 1
Catenary elements. A table of (Witmer), 633
Cement research. Results of recent, and their partial application (Carlson), 1
Chemistry. Energy hump in (Bancroft & Magoffin), 283, 475
Circuits, variable. Solution of by matrices (Pipes), 767
Clay, bleach, solubility. A study of (Nutting), 339
Cloud chamber investigations of some cosmic-ray interactions with matter (Locher), 555
Corona in a closed space. Pressure due to (Gemant), 603
Cosmic-ray interactions with matter. Cloud chamber investigations of some (Locher), 555
Current topics: 54, 76, 102, 104, 114, 122, 130, 152, 216, 261, 282, 310, 338, 380, 388, 409, 474, 500, 537, 554, 602, 614, 632, 696, 766, 778, 801

Debye, Peter: Structure in electrolytic solutions, 135
Die casting, counter gravity, of high melting-point metals (Wetherill), 153

Electrolytic solutions. Structure in (Debye), 135
Electrons, equivalent, and their spectroscopic terms (Shudeman), 501
Energy hump in chemistry (Bancroft & Magoffin), 283, 475
Explanations (Merrill), 103
Exposure in photographic printing. Devices for the photoelectric control of (Tuttle), 615

Franklin Institute.
Bartol Research Foundation:
Communication, no. 95: Cloud chamber investigations of some cosmic-ray interactions with matter (Locher), 555
Notes, 105; 231, 381
Report on the work, 1936–1937, 415
Biochemical Research Foundation. The microchemical laboratory of (Alber & Harand), 729
Board of Managers, Resolutions passed on the occasion of the death

of Henry Howson, vice president, 790
By-Laws, 657
Library Notes: 123, 251, 397, 527, 663, 790
Medal day meeting, 217
Monthly meeting: October 20, 1937, 655; November 17, 1937, 789
Science and the Arts Committee. Abstract of Proceedings: June 9, 1937, 123
Franklin Institute, story of (Wright) 77

Gemant, A.: The pressure due to corona in a closed space, 603
Goodman, Nathan G.: Earliest wireless experiments in America, 311
Gunn, Ross: A quantitative study of mountain building on an unsymmetrical earth, 19

Harand, Josef & Herbert K. Alber: The microchemical laboratory of the Bio-chemical Research Foundation, 729

Insulation, high voltage. Limitations of (Whitehead), 363

Kurtz, S. S., Jr. & A. L. Ward: The refractivity intercept and the specific refraction equation of Newton—II, 583, 697

Land, Edwin H.: Polariod and the headlight problem, 269
Locher, Gordon L.: Cloud chamber investigations of some cosmic-ray interactions with matter, 555

Magoffin, James E. & Wilder D. Bancroft: The energy hump in chemistry I, II, 283, 475
Matrices. Solution of variable circuits by (Pipes), 767
McDowell, C. S.: Building the 200-inch telescope, 675
Materials. Particulate (Roller). Errata, 800
Mercury vapor grid-controlled tubes; Their electric control by a phase-shifting network (Strelzoff), 55, 191
Merrill, A. A.: Explanations, 103
Microchemical Laboratory of the Biochemical Research Foundation (Alber & Harand), 729
Millikan, Robert A.: Exploring the stratosphere for new electrical effects, 145
Mountain building. A quantitative study of (Gunn), 19

National Bureau of Standards: Notes, 115; 243; 389, 519, 645, 779
Nutting, P. G.: A study of bleach clay solubility, 339

Philadelphia City Hall. Investigation of vibration of (Shrader), 757
Photoelectric photometry in printing of amateur negatives (Tuttle), 315
Photographic printing. Devices for the photoelectric control of exposure in (Tuttle), 615
Photometry, photoelectric (Tuttle), 315
Pipes, Louis A.: Solution of variable circuits by matrices, 767
Polariod and the headlight problem (Land), 269
Publications received: 129, 259, 408, 535, 673, 799

Refractivity intercept and the specific refraction equation of Newton—II (Kurtz & Ward), 583, 697
Roller, Paul S.: Law of size distribution. Errata, 800

Shrader, J. E.: Investigation of vibration of City Hall in Philadelphia and of the subway structure beneath, 757
Shudeman, C. L. B.: Equivalent electrons and their spectroscopic terms, 501

Stratosphere. Exploring the, for new electrical effects (Millikan), 145
Strelzoff, J. A.: Mercury vapor grid-controlled tubes; Their electric control by a phase-shifting network, 55, 191
Swann, W. F. G.: Report on the work of the Bartol Research Foundation, 415

Telescope, 200-inch. Building the (McDowell), 675
Thomson, Eihu. Earliest wireless experiments in America (Goodman), 311
Tuttle, Clifton: Devices for the photoelectric control of exposure in photographic printing, 615
Tuttle, Clifton M.: Photoelectric photometry in printing of amateur negatives, 315

Vacuum tubes. Mercury vapor grid-controlled tubes (Strelzoff), 55, 191
Vitamin B_1. The quest of (Williams), 541

Ward, A. L. & S. S. Kurtz, Jr.: The refractivity intercept and the specific refraction equation of Newton—II, 583, 697
Wetherill, Samuel P.: Counter gravity die casting of high melting-point metals, 153
Whitehead, J. B.: Limitations of high voltage insulation, 363
Williams, R. R.: The quest of vitamin B_1, 541
Wireless experiments. Earliest in America (Goodman), 311
Witmer, Francis P.: A table of catenary elements, 633
Wright, Sydney L.: The story of the Franklin Institute, 77